Aho-Corasick Algorithm for Pattern Searching

Difficulty Level : Expert Last Updated : 27 May, 2021

Given an input text and an array of k words, arr[], find all occurrences of all words in the input text. Let **n** be the length of text and **m** be the total number characters in all words, i.e. m = length(arr[0]) + length(arr[1]) + … + length(arr[k-1]). Here **k** is total numbers of input words.

Example:

```
Input: text = "ahishers"
       arr[] = {"he", "she", "hers", "his"}

Output:
   Word his appears from 1 to 3
   Word he appears from 4 to 5
   Word she appears from 3 to 5
   Word hers appears from 4 to 7
```

If we use a linear time searching algorithm like **KMP**, then we need to one by one search all words in text[]. This gives us total time complexity as O(n + length(word[0]) + O(n + length(word[1]) + O(n + length(word[2]) + … O(n + length(word[k-1]). This time complexity can be written as ***O(n*k + m)***.

Aho-Corasick Algorithm finds all words in ***O(n + m + z)*** time where **z** is total number of occurrences of words in text. The Aho–Corasick string matching algorithm formed the basis of the original Unix command fgrep.

- **Prepocessing :** Build an automaton of all words in arr[] The automaton has mainly three functions:

```
Go To :   This function simply follows edges
          of Trie of all words in arr[]. It is
          represented as 2D array g[][] where
          we store next state for current state
          and character.

Failure : This function stores all edges that are
          followed when current character doesn't
```

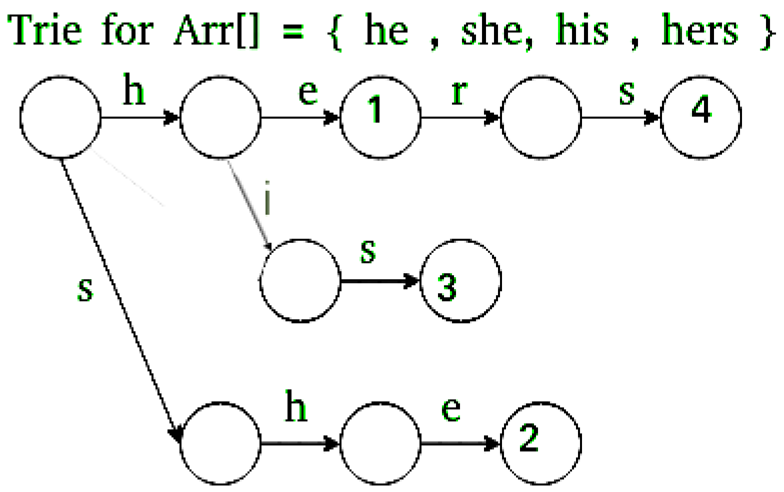
```
            have edge in Trie.  It is represented as
            1D array f[] where we store next state for
            current state.

 Output :   Stores indexes of all words that end at
            current state. It is represented as 1D
            array o[] where we store indexes
            of all matching words as a bitmap for
            current state.
```

- **Matching :** Traverse the given text over built automaton to find all matching words.

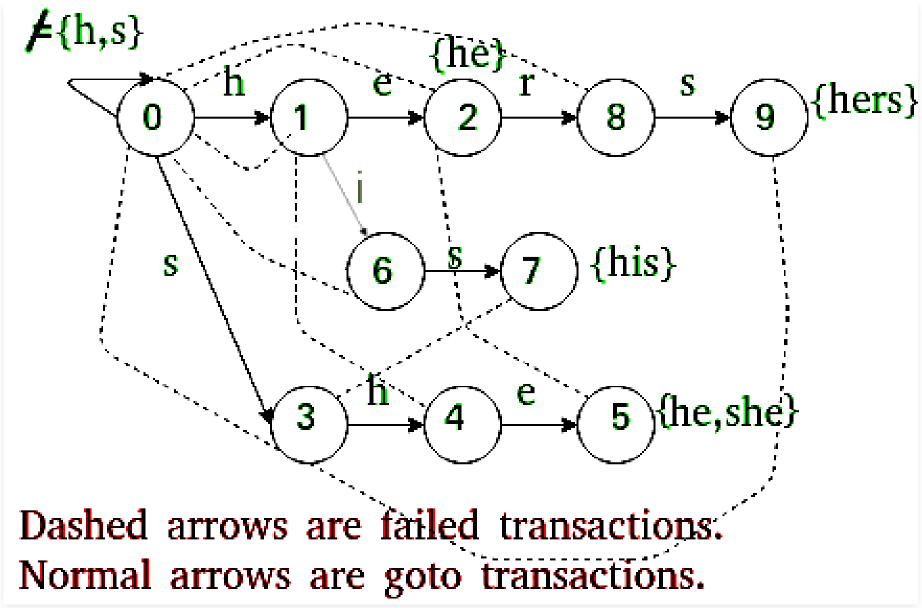
Preprocessing:

- We first Build a Trie (or Keyword Tree) of all words.



Trie

- This part fills entries in goto g[][] and output o[].
- Next we extend Trie into an automaton to support linear time matching.


≠{h,s}
h
e
{he}
r
s
{hers}
i
s
{his}
s
h
e
{he,she}
0
1
2
8
9
6
7
3
4
5
Dashed arrows are failed transactions.
Normal arrows are goto transactions.

- This part fills entries in failure f[] and output o[].

Go to :
We build Trie. And for all characters which don't have an edge at root, we add an edge back to root.
Failure :
For a state s, we find the longest proper suffix which is a proper prefix of some pattern. This is done using Breadth First Traversal of Trie.
Output :
For a state s, indexes of all words ending at s are stored. These indexes are stored as bitwise map (by doing bitwise OR of values). This is also computing using Breadth First Traversal with Failure.

Below is the implementation of Aho-Corasick Algorithm

C++

Java

```
// Java program for implementation of
// Aho Corasick algorithm for String
// matching
import java.util.*;

class GFG{

// Max number of states in the matching
// machine. Should be equal to the sum
// of the length of all keywords.
static int MAXS = 500;

// Maximum number of characters
// in input alphabet
static int MAXC = 26;

// OUTPUT FUNCTION IS IMPLEMENTED USING out[]
// Bit i in this mask is one if the word with
// index i appears when the machine enters
// this state.
static int []out = new int[MAXS];

// FAILURE FUNCTION IS IMPLEMENTED USING f[]
static int []f = new int[MAXS];

// GOTO FUNCTION (OR TRIE) IS
// IMPLEMENTED USING g[][]
static int [][]g = new int[MAXS][MAXC];

// Builds the String matching machine.
// arr -   array of words. The index of each keyword is important:
//         "out[state] & (1 << i)" is > 0 if we just found word[i]
//         in the text.
// Returns the number of states that the built machine has.
// States are numbered 0 up to the return value - 1, inclusive.
static int buildMatchingMachine(String arr[], int k)
{

    // Initialize all values in output function as 0.
    Arrays.fill(out, 0);

    // Initialize all values in goto function as -1.
    for(int i = 0; i < MAXS; i++)
        Arrays.fill(g[i], -1);

    // Initially, we just have the 0 state
    int states = 1;

    // Convalues for goto function, i.e., fill g[][]
    // This is same as building a Trie for arr[]
    for(int i = 0; i < k; ++i)
    {
        String word = arr[i];
        int currentState = 0;

        // Insert all characters of current
        // word in arr[]
        for(int j = 0; j < word.length(); ++j)
        {
            int ch = word.charAt(j) - 'a';

            // Allocate a new node (create a new state)
            // if a node for ch doesn't exist.
            if (g[currentState][ch] == -1)
                g[currentState][ch] = states++;

            currentState = g[currentState][ch];
        }

        // Add current word in output function
        out[currentState] |= (1 << i);
    }

    // For all characters which don't have
    // an edge from root (or state 0) in Trie,
    // add a goto edge to state 0 itself
    for(int ch = 0; ch < MAXC; ++ch)
        if (g[0][ch] == -1)
            g[0][ch] = 0;

    // Now, let's build the failure function
    // Initialize values in fail function
    Arrays.fill(f, -1);

    // Failure function is computed in
    // breadth first order
    // using a queue
    Queue<Integer> q = new LinkedList<>();

    // Iterate over every possible input
    for(int ch = 0; ch < MAXC; ++ch)
    {

        // All nodes of depth 1 have failure
        // function value as 0. For example,
        // in above diagram we move to 0
        // from states 1 and 3.
        if (g[0][ch] != 0)
        {
            f[g[0][ch]] = 0;
            q.add(g[0][ch]);
        }
    }

    // Now queue has states 1 and 3
    while (!q.isEmpty())
    {

        // Remove the front state from queue
        int state = q.peek();
        q.remove();

        // For the removed state, find failure
        // function for all those characters
        // for which goto function is
        // not defined.
```

```
            for(int ch = 0; ch < MAXC; ++ch)
            {

                // If goto function is defined for
                // character 'ch' and 'state'
                if (g[state][ch] != -1)
                {

                    // Find failure state of removed state
                    int failure = f[state];

                    // Find the deepest node labeled by proper
                    // suffix of String from root to current
                    // state.
                    while (g[failure][ch] == -1)
                          failure = f[failure];

                    failure = g[failure][ch];
                    f[g[state][ch]] = failure;

                    // Merge output values
                    out[g[state][ch]] |= out[failure];

                    // Insert the next level node
                    // (of Trie) in Queue
                    q.add(g[state][ch]);
                }
            }
        }
        return states;
    }

    // Returns the next state the machine will transition to using goto
    // and failure functions.
    // currentState - The current state of the machine. Must be between
    //                0 and the number of states - 1, inclusive.
    // nextInput - The next character that enters into the machine.
    static int findNextState(int currentState, char nextInput)
    {
        int answer = currentState;
        int ch = nextInput - 'a';

        // If goto is not defined, use
        // failure function
        while (g[answer][ch] == -1)
            answer = f[answer];

        return g[answer][ch];
    }

    // This function finds all occurrences of
    // all array words in text.
    static void searchWords(String arr[], int k,
```

```java
                        String text)
{

    // Preprocess patterns.
    // Build machine with goto, failure
    // and output functions
    buildMatchingMachine(arr, k);

    // Initialize current state
    int currentState = 0;

    // Traverse the text through the
    // nuilt machine to find all
    // occurrences of words in arr[]
    for(int i = 0; i < text.length(); ++i)
    {
        currentState = findNextState(currentState,
                                     text.charAt(i));

        // If match not found, move to next state
        if (out[currentState] == 0)
             continue;

        // Match found, print all matching
        // words of arr[]
        // using output function.
        for(int j = 0; j < k; ++j)
        {
            if ((out[currentState] & (1 << j)) > 0)
            {
                System.out.print("Word " +  arr[j] +
                                 " appears from " +
                                 (i - arr[j].length() + 1) +
                                 " to " +  i + "\n");
            }
        }
    }
}

// Driver code
public static void main(String[] args)
{
    String arr[] = { "he", "she", "hers", "his" };
    String text = "ahishers";
    int k = arr.length;

    searchWords(arr, k, text);
}
}

// This code is contributed by Princi Singh
```

C#

Python3

Output

```
Word his appears from 1 to 3
Word he appears from 4 to 5
Word she appears from 3 to 5
Word hers appears from 4 to 7
```

Source:
http://www.cs.uku.fi/~kilpelai/BSA05/lectures/slides04.pdf
This article is contributed by **Ayush Govil**. Please write comments if you find anything incorrect, or you want to share more information about the topic discussed above