Aho-Corasick Algorithm for Pattern Searching

Difficulty Level : Expert • Last Updated : 05 Nov, 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.

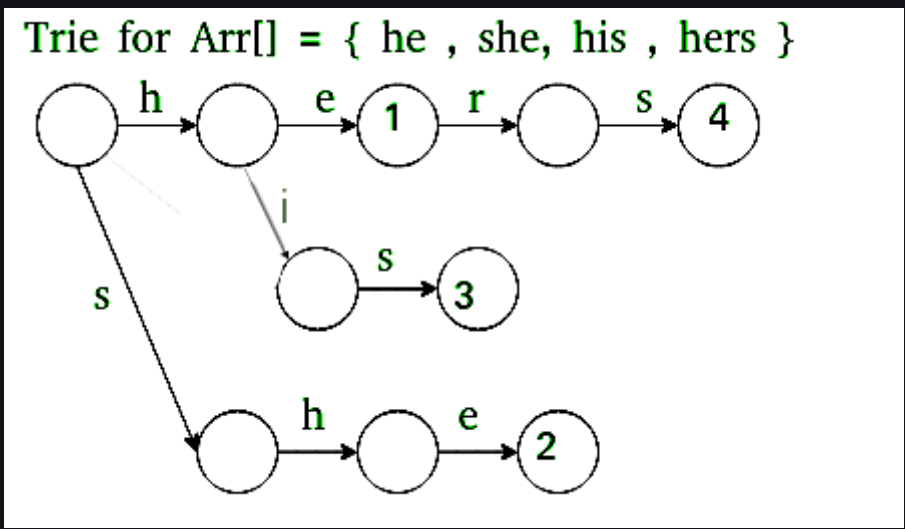
Preprocessing : Build an automaton of all words in arr[] The automaton has mainly three functions:

```
           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.

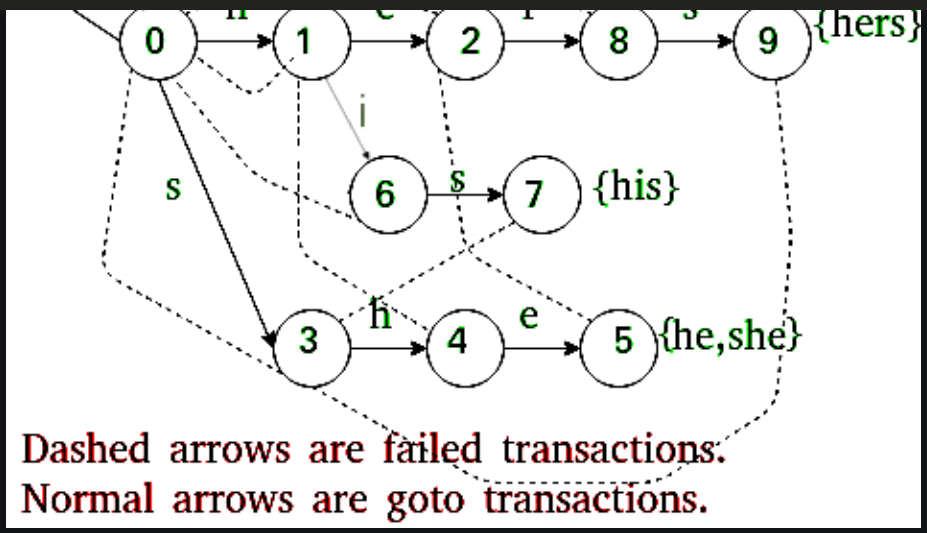
Preprocessing:

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



Trie

This part fills entries in goto g[][] and output o[].



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

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++

```
// C++ program for implementation of Aho Corasick algorithm
// for string matching
using namespace std;
#include <bits/stdc++.h>

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

```
int out[MAXS];

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

// GOTO FUNCTION (OR TRIE) IS IMPLEMENTED USING g[][]
int g[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.
int buildMatchingMachine(string arr[], int k)
{
    // Initialize all values in output function as 0.
    memset(out, 0, sizeof out);

    // Initialize all values in goto function as -1.
    memset(g, -1, sizeof g);

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

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

        // Insert all characters of current word in arr[]
        for (int j = 0; j < word.size(); ++j)
        {
            int ch = word[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 <<
```

```
        if (g[0][ch] == -1)
            g[0][ch] = 0;

    // Now, let's build the failure function

    // Initialize values in fail function
    memset(f, -1, sizeof f);

    // Failure function is computed in breadth first order
    // using a queue
    queue<int> q;

     // 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.push(g[0][ch]);
        }
    }

    // Now queue has states 1 and 3
    while (q.size())
    {
        // Remove the front state from queue
        int state = q.front();
        q.pop();

        // 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.
```

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

                // Insert the next level node (of Trie) in Queue
                q.push(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.
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.
void searchWords(string arr[], int k, 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 built machine to find
    // all occurrences of words in arr[]
    for (int i = 0; i < text.size(); ++i)
    {
        currentState = findNextState(currentState, text[i]);

        // If match not found, move to next state
```

```
        {
            if (out[currentState] & (1 << j))
            {
                cout << "Word " << arr[j] << " appears from "
                     << i - arr[j].size() + 1 << " to " << i << endl;
            }
        }
    }
}

// Driver program to test above
int main()
{
    string arr[] = {"he", "she", "hers", "his"};
    string text = "ahishers";
    int k = sizeof(arr)/sizeof(arr[0]);

    searchWords(arr, k, text);

    return 0;
}
```

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];
```

```
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 do[illegible]ave
```

```
// 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]
```

```
                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,
                        String text)
{

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

    // Initialize current state
    int currentState = 0;
```

```
                                        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
```

Python3

```
# Python program for implementation of
# Aho-Corasick algorithm for string matching

# defaultdict is used only for storing the final output
# We will return a dictionary where key is the matched word
# and value is the list of indexes of matched word
from collections import defaultdic
```

```
        # Should be equal to the sum of the length of all keywords.
        self.max_states = sum([len(word) for word in words])

        # Maximum number of characters.
        # Currently supports only alphabets [a,z]
        self.max_characters = 26

        # OUTPUT FUNCTION IS IMPLEMENTED USING out []
        # Bit i in this mask is 1 if the word with
        # index i appears when the machine enters this state.
        # Lets say, a state outputs two words "he" and "she" and
        # in our provided words list, he has index 0 and she has index 3
        # so value of out[state] for this state will be 1001
        # It has been initialized to all 0.
        # We have taken one extra state for the root.
        self.out = [0]*(self.max_states+1)

        # FAILURE FUNCTION IS IMPLEMENTED USING fail []
        # There is one value for each state + 1 for the root
        # It has been initialized to all -1
        # This will contain the fail state value for each state
        self.fail = [-1]*(self.max_states+1)

        # GOTO FUNCTION (OR TRIE) IS IMPLEMENTED USING goto [[]]
        # Number of rows = max_states + 1
        # Number of columns = max_characters i.e 26 in our case
        # It has been initialized to all -1.
        self.goto = [[-1]*self.max_characters for _ in range(self.max_sta

        # Convert all words to lowercase
        # so that our search is case insensitive
        for i in range(len(words)):
            words[i] = words[i].lower()

        # All the words in dictionary which will be used to create Trie
        # The index of each keyword is important:
        # "out[state] & (1 << i)" is > 0 if we just found word[i]
        # in the text.
        self.words = words

        # Once the Trie has been built, it will contain the number
        # of nodes in Trie which is total number of states required <= max
        self.states_count = self.__build_matching_machine()


    # Builds the String matching machine.
    # Returns the number of states that the built machine has.
```

```
        # Convalues for goto function, i.e., fill goto
        # This is same as building a Trie for words[]
        for i in range(k):
            word = self.words[i]
            current_state = 0

            # Process all the characters of the current word
            for character in word:
                ch = ord(character) - 97 # Ascii value of 'a' = 97

                # Allocate a new node (create a new state)
                # if a node for ch doesn't exist.
                if self.goto[current_state][ch] == -1:
                    self.goto[current_state][ch] = states
                    states += 1

                current_state = self.goto[current_state][ch]

            # Add current word in output function
            self.out[current_state] |= (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 ch in range(self.max_characters):
            if self.goto[0][ch] == -1:
                self.goto[0][ch] = 0

        # Failure function is computed in
        # breadth first order using a queue
        queue = []

        # Iterate over every possible input
        for ch in range(self.max_characters):

            # 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 self.goto[0][ch] != 0:
                self.fail[self.goto[0][ch]] = 0
                queue.append(self.goto[0][ch])

        # Now queue has states 1 and 3
        while queue:
```

```
            for ch in range(self.max_characters):

                # If goto function is defined for
                # character 'ch' and 'state'
                if self.goto[state][ch] != -1:

                    # Find failure state of removed state
                    failure = self.fail[state]

                    # Find the deepest node labeled by proper
                    # suffix of String from root to current state.
                    while self.goto[failure][ch] == -1:
                        failure = self.fail[failure]

                    failure = self.goto[failure][ch]
                    self.fail[self.goto[state][ch]] = failure

                    # Merge output values
                    self.out[self.goto[state][ch]] |= self.out[failure]

                    # Insert the next level node (of Trie) in Queue
                    queue.append(self.goto[state][ch])

        return states


    # Returns the next state the machine will transition to using goto
    # and failure functions.
    # current_state - The current state of the machine. Must be between
    #             0 and the number of states - 1, inclusive.
    # next_input - The next character that enters into the machine.
    def __find_next_state(self, current_state, next_input):
        answer = current_state
        ch = ord(next_input) - 97 # Ascii value of 'a' is 97

        # If goto is not defined, use
        # failure function
        while self.goto[answer][ch] == -1:
            answer = self.fail[answer]

        return self.goto[answer][ch]


    # This function finds all occurrences of all words in text.
    def search_words(self, text):
        # Convert the text to lowercase to make search case insensitive
        text = text.lower()
```

```
        # Value is a list of all occurrences start index
        result = defaultdict(list)

        # Traverse the text through the built machine
        # to find all occurrences of words
        for i in range(len(text)):
            current_state = self.__find_next_state(current_state, text[i])

            # If match not found, move to next state
            if self.out[current_state] == 0: continue

            # Match found, store the word in result dictionary
            for j in range(len(self.words)):
                if (self.out[current_state] & (1<<j)) > 0:
                    word = self.words[j]

                    # Start index of word is (i-len(word)+1)
                    result[word].append(i-len(word)+1)

        # Return the final result dictionary
        return result

# Driver code
if __name__ == "__main__":
    words = ["he", "she", "hers", "his"]
    text = "ahishers"

    # Create an Object to initialize the Trie
    aho_chorasick = AhoCorasick(words)

    # Get the result
    result = aho_chorasick.search_words(text)

    # Print the result
    for word in result:
        for i in result[word]:
            print("Word", word, "appears from", i, "to", i+len(word)-1)

# This code is contributed by Md Azharuddin
```

C#

```
// C# program for implementation of
// Aho Corasick algorithm for String
// 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.
    for(int i = 0; i < outt.Length; i++)
        outt[i] = 0;

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

```
        for(int j = 0; j < word.Length; ++j)
        {
            int ch = word[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
        outt[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
    for(int i = 0; i < MAXC; i++)
        f[i] = 0;

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

    // 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.Enqueue(g[0, ch]);
        }
    }
```

```
        int state = q.Peek();
        q.Dequeue();

        // 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
                outt[g[state, ch]] |= outt[failure];

                // Insert the next level node
                // (of Trie) in Queue
                q.Enqueue(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,
```

```
    // 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,
                        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
    // built machine to find all
    // occurrences of words in []arr
    for(int i = 0; i < text.Length; ++i)
    {
        currentState = findNextState(currentState,
                                     text[i]);

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

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

```
    String text = "ahishers";
    int k = arr.Length;

    searchWords(arr, k, text);
}
}

// This code is contributed by Amit Katiyar
```

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