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Cocke–Younger–Kasami (CYK)



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Grammar denotes the syntactical rules for conversation in natural language. But in the theory of formal language, grammar is defined as a set of rules that can generate strings. The set of all strings that can be generated from a grammar is called the language of the grammar.

Context Free Grammar:

We are given a Context Free Grammar $G = (V, X, R, S)$ and a string w , where:

- V is a finite set of variables or non-terminal symbols,
- X is a finite set of terminal symbols,
- R is a finite set of rules,
- S is the start symbol, a distinct element of V , and
- V and X are assumed to be disjoint sets.

The **Membership problem** is defined as: Grammar G generates a language $L(G)$. Is the given string a member of $L(G)$?

Chomsky Normal Form:

A Context Free Grammar G is in Chomsky Normal Form (CNF) if each rule if each rule of G is of the form:

- $A \rightarrow BC$, [with at most two non-terminal symbols on the RHS]
- $A \rightarrow a$, or [one terminal symbol on the RHS]
- $S \rightarrow \text{nullstring}$, [null string]

Cocke–Younger–Kasami Algorithm

It is used to solve the membership problem using a [dynamic programming](#) approach.

The algorithm is based on the principle that the solution to problem $[i, j]$ can be constructed from solution to subproblem $[i, k]$ and solution to subproblem $[k, j]$. The algorithm requires the Grammar G to be in Chomsky Normal Form (CNF). Note that any Context-Free Grammar can be systematically [converted to CNF](#). This restriction is employed so that each problem can only be divided into two subproblems and not more – to bound the time complexity.

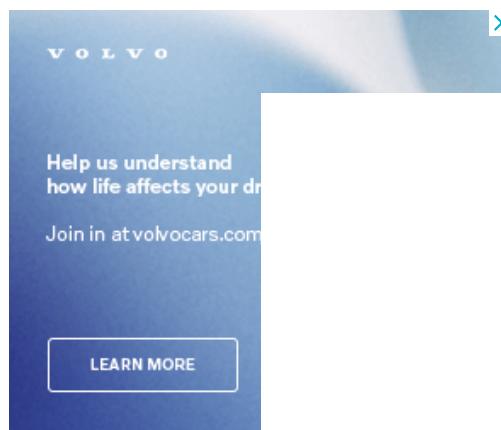
How does the CYK Algorithm work?

For a string of length N , construct a table T of size $N \times N$. Each cell in the table $T[i, j]$ is the set of all constituents that can produce the substring spanning from position i to j . The process involves filling the table with the solutions to the subproblems encountered in the bottom-up parsing process. Therefore, cells will be filled from left to right and bottom to top.

	1	2	3	4	5
1	[1, 1]	[1, 2]	[1, 3]	[1, 4]	[1, 5]
2		[2, 2]	[2, 3]	[2, 4]	[2, 5]
3			[3, 3]	[3, 4]	[3, 5]
4				[4, 4]	[4, 5]



In $T[i, j]$, the row number i denotes the start index and the column number j denotes the end index.



$A \in T[i, j]$ if and only if $B \in T[i, k], C \in T[k, j]$ and $A \rightarrow BC$ is a rule of G

The algorithm considers every possible subsequence of letters and adds K to $T[i, j]$ if the sequence of letters starting from i to j can be generated from the non-terminal K . For subsequences of length 2 and greater, it considers every possible partition of the subsequence into two parts, and checks if there is a rule of the form $A \rightarrow BC$ in the grammar where B and C can generate the two parts respectively, based on already existing entries in T . The sentence can be produced by the grammar only if the entire string is matched by the start symbol, i.e, if S is a member of $T[1, n]$.

Consider a sample grammar in Chomsky Normal Form:

```

NP  --> Det | Nom
Nom --> AP | Nom
AP   --> Adv | A
Det  --> a | an
Adv  --> very | extremely
AP   --> heavy | orange | tall
A    --> heavy | orange | tall | muscular
Nom --> book | orange | man
  
```

Now consider the phrase, “**a very heavy orange book**“:

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a(1) very(2) heavy (3) orange(4) book(5)

Let us start filling up the table from left to right and bottom to top, according to the rules described above:

	1 a	2 very	3 heavy	4 orange	5 book
1 a	Det	–	–	NP	NP
2 very		Adv	AP	Nom	Nom
3 heavy			A, AP	Nom	Nom
4 orange				Nom, A, AP	Nom
5 book					Nom

The table is filled in the following manner:

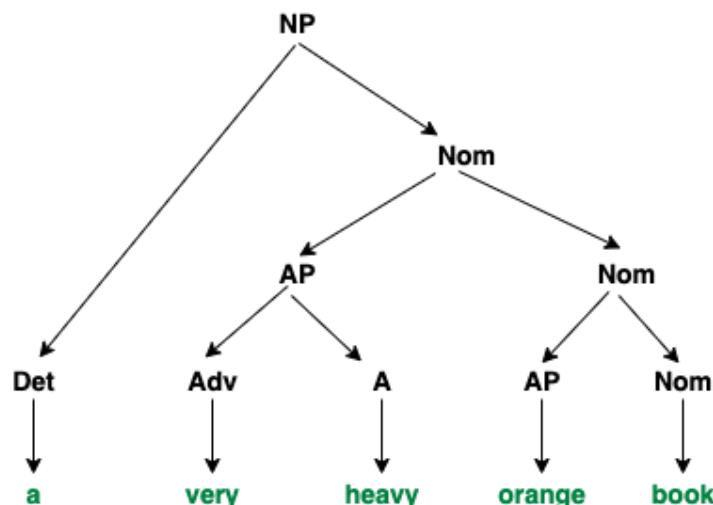
1. $T[1, 1] = \{\text{Det}\}$ as $\text{Det} \rightarrow a$ is one of the rules of the grammar.
2. $T[2, 2] = \{\text{Adv}\}$ as $\text{Adv} \rightarrow \text{very}$ is one of the rules of the grammar.
3. $T[1, 2] = \{\}$ as no matching rule is observed.
4. $T[3, 3] = \{\text{A, AP}\}$ as $\text{A} \rightarrow \text{very}$ and $\text{AP} \rightarrow \text{very}$ are rules of the grammar.
5. $T[2, 3] = \{\text{AP}\}$ as $\text{AP} \rightarrow \text{Adv}$ ($T[2, 2]$) A ($T[3, 3]$) is a rule of the grammar.
6. $T[1, 3] = \{\}$ as no matching rule is observed.
7. $T[4, 4] = \{\text{Nom, A, AP}\}$ as $\text{Nom} \rightarrow \text{orange}$ and $\text{A} \rightarrow \text{orange}$ and $\text{AP} \rightarrow \text{orange}$ are rules

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9. $T[2, 4] = \{\text{Nom}\}$ as Nom $\rightarrow AP(T[2, 3])$ Nom ($T[4, 4]$) is a rule of the grammar.
10. $T[1, 4] = \{\text{NP}\}$ as NP $\rightarrow Det(T[1, 1])$ Nom ($T[2, 4]$) is a rule of the grammar.
11. $T[5, 5] = \{\text{Nom}\}$ as Nom $\rightarrow \text{book}$ is a rule of the grammar.
12. $T[4, 5] = \{\text{Nom}\}$ as Nom $\rightarrow AP(T[4, 4])$ Nom ($T[5, 5]$) is a rule of the grammar.
13. $T[3, 5] = \{\text{Nom}\}$ as Nom $\rightarrow AP(T[3, 3])$ Nom ($T[4, 5]$) is a rule of the grammar.
14. $T[2, 5] = \{\text{Nom}\}$ as Nom $\rightarrow AP(T[2, 3])$ Nom ($T[4, 5]$) is a rule of the grammar.
15. $T[1, 5] = \{\text{NP}\}$ as NP $\rightarrow Det(T[1, 1])$ Nom ($T[2, 5]$) is a rule of the grammar.

We see that $T[1][5]$ has **NP**, the start symbol, which means that this phrase is a member of the language of the grammar G .

The parse tree of this phrase would look like this:



Let us look at another example phrase, “a **very tall extremely muscular man**”:

a(1) very(2) tall(3) extremely(4) muscular(5) man(6)

We will now use the CYK algorithm to find if this string is a member of the grammar G :

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	1 a	2 very	3 tall	4 extremely	5 muscular	6 man	
1 a	Det	-	-	-	-	-	NP
2 very		Adv	AP	-	-	-	Nom
3 tall			AP, A	-	-	-	Nom
4 extremely				Adv	AP	-	Nom
5 muscular					A	-	
6 man						-	Nom

We see that $T[1][6]$ has **NP**, the start symbol, which means that this phrase is a member of the language of the grammar G.

Below is the implementation of the above algorithm:

C++

```
// C++ implementation for the
// CYK Algorithm

#include<bits/stdc++.h>
using namespace std;

// Non-terminals symbols
vector<string> terminals,non_terminals;
```

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```

// function to perform the CYK Algorithm
void cykParse(vector<string> w)
{
    int n = (int)w.size();

    // Initialize the table
    map<int, map<int, set<string>>> T;

    // Filling in the table
    for(int j=0;j<n;j++)
    {

        // Iterate over the rules
        for(auto x:R)
        {
            string lhs = x.first;
            vector<vector<string>> rule = x.second;

            for(auto rhs:rule)
            {

                // If a terminal is found
                if(rhs.size() == 1 && rhs[0] == w[j])
                    T[j][j].insert(lhs);
            }
        }

        for(int i=j;i>=0;i--)
        {

            // Iterate over the range from i to j
            for(int k = i;k<=j;k++)
            {

                // Iterate over the rules
                for(auto x:R)
                {
                    string lhs = x.first;
                    vector<vector<string>> rule = x.second;

                    for(auto rhs:rule)
                    {
                        // If a terminal is found
                        if(rhs.size()==2 && T[i][k].find(rhs[0])!=T[i][k].end() && T[k+1][j].find(rhs[1])
                            T[i][j].insert(lhs);
                    }
                }
            }
        }
    }
}

```

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```

// of given grammar
if(T[0][n-1].size()!=0)
    cout << "True\n";
else
    cout << "False\n";
}

// Driver Code
int main()
{
    // terminal symbols
    terminals = {"book", "orange", "man",
                  "tall", "heavy",
                  "very", "muscular"};

    // non terminal symbols
    non_terminals = {"NP", "Nom", "Det", "AP",
                     "Adv", "A"};

    // Rules
    R["NP"]={{"Det", "Nom"}};
    R["Nom"]={{"AP", "Nom"}, {"book",
                               {"orange"}, {"man"} }};
    R["AP"]={{"Adv", "A"}, {"heavy",
                               {"orange"}, {"tall"} }};
    R["Det"]={{"a"}};
    R["Adv"]={{"very"}, {"extremely"}};
    R["A"]={{"heavy"}, {"orange"}, {"tall"}, {"muscular"}};

    // Given String
    vector<string> w = {"a", "very", "heavy", "orange", "book"};

    // Function Call
    cykParse(w);

    return 0;
}

```

Java

```

import java.util.*;

class GFG
{

    // Non-terminals symbols
    static List<String> terminals = new ArrayList<>();
    static List<String> non_terminals = new ArrayList<>();

```

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```

= new HashMap<>();

// function to perform the CYK Algorithm
static void cykParse(List<String> w)
{
    int n = w.size();

    // Initialize the table
    Map<Integer, Map<Integer, Set<String> > > T
    = new HashMap<>();

    // Filling in the table
    for (int j = 0; j < n; j++) {

        // Iterate over the rules
        for (Map.Entry<String, List<List<String> > > x :
            R.entrySet()) {
            String lhs = x.getKey();
            List<List<String> > rule = x.getValue();

            for (List<String> rhs : rule) {

                // If a terminal is found
                if (rhs.size() == 1
                    && rhs.get(0).equals(w.get(j))) {
                    if (T.get(j) == null)
                        T.put(j, new HashMap<>());
                    T.get(j)
                        .computeIfAbsent(
                            j, k -> new HashSet<>())
                        .add(lhs);
                }
            }
        }
        for (int i = j; i >= 0; i--) {

            // Iterate over the range from i to j
            for (int k = i; k <= j; k++) {

                // Iterate over the rules
                for (Map.Entry<String,
                    List<List<String> > > x :
                    R.entrySet()) {
                    String lhs = x.getKey();
                    List<List<String> > rule
                    = x.getValue();

                    for (List<String> rhs : rule) {
                        // If a terminal is found
                        if (rhs.size() == 2
                            && T.get(i) != null
                            && T.get(i).get(k) != null

```

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```

        && T.get(k + 1) != null
        && T.get(k + 1).get(j)
        != null
        && T.get(k + 1)
        .get(j)
        .contains(
            rhs.get(1))) {
        if (T.get(i) == null)
            T.put(i,
                  new HashMap<>());
        if (T.get(i).get(j) == null)
            T.get(i).put(
                j, new HashSet<>());
        T.get(i).get(j).add(lhs);
    }
}
}
}
}
}

// If word can be formed by rules
// of given grammar
if (T.get(0) != null && T.get(0).get(n - 1) != null
    && T.get(0).get(n - 1).size() != 0)
    System.out.println("True");
else
    System.out.println("False");
}

// Driver Code
public static void main(String[] args)
{
    // terminal symbols
    terminals
        = Arrays.asList("book", "orange", "man", "tall",
                        "heavy", "very", "muscular");

    // non terminal symbols
    non_terminals = Arrays.asList("NP", "Nom", "Det",
                                  "AP", "Adv", "A");

    // Rules
    R.put("NP",
          Arrays.asList(Arrays.asList("Det", "Nom")));
    R.put("Nom",
          Arrays.asList(Arrays.asList("AP", "Nom"),
                      Arrays.asList("book"),
                      Arrays.asList("orange"),
                      Arrays.asList("man")));
    R.put("AP", Arrays.asList(Arrays.asList("Adv", "A"),
                             Arrays.asList("heavv")));
}

```

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```

R.put("Det", Arrays.asList(Arrays.asList("a")));
R.put("Adv",
      Arrays.asList(Arrays.asList("very"),
                  Arrays.asList("extremely")));
R.put("A",
      Arrays.asList(Arrays.asList("heavy"),
                  Arrays.asList("orange"),
                  Arrays.asList("tall"),
                  Arrays.asList("muscular")));

// Given String
List<String> w = Arrays.asList("a", "very", "heavy",
                                "orange", "book");

// Function Call
cykParse(w);
}

}

// This code is contributed by lokeshpotta20

```

Python3

```

# Python implementation for the
# CYK Algorithm

# Non-terminal symbols
non_terminals = ["NP", "Nom", "Det", "AP",
                 "Adv", "A"]
terminals = ["book", "orange", "man",
             "tall", "heavy",
             "very", "muscular"]

# Rules of the grammar
R = {
    "NP": [[["Det", "Nom"]]],
    "Nom": [[[["AP", "Nom"], ["book"]],
              ["orange"], ["man"]]],
    "AP": [[[["Adv", "A"], ["heavy"]],
              ["orange"], ["tall"]]],
    "Det": [[[["a"]]],
    "Adv": [[[["very"], ["extremely"]]],
    "A": [[[["heavy"], ["orange"], ["tall"],
              ["muscular"]]]]
}

# Function to perform the CYK Algorithm
def cykParse(w):
    n = len(w)

```

[View on GitHub](#)

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```

# Filling in the table
for j in range(0, n):

    # Iterate over the rules
    for lhs, rule in R.items():
        for rhs in rule:

            # If a terminal is found
            if len(rhs) == 1 and \
                rhs[0] == w[j]:
                T[j][j].add(lhs)

    for i in range(j, -1, -1):

        # Iterate over the range i to j + 1
        for k in range(i, j + 1):

            # Iterate over the rules
            for lhs, rule in R.items():
                for rhs in rule:

                    # If a terminal is found
                    if len(rhs) == 2 and \
                        rhs[0] in T[i][k] and \
                        rhs[1] in T[k + 1][j]:
                        T[i][j].add(lhs)

    # If word can be formed by rules
    # of given grammar
    if len(T[0][n-1]) != 0:
        print("True")
    else:
        print("False")

# Driver Code

# Given string
w = "a very heavy orange book".split()

# Function Call
cykParse(w)

```

C#

```

// C# program to implement above approach
using System;
using System.Collections;
using System.Collections.Generic;

class GFG

```

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```

// static List<string> terminals = new List<string>();
// static List<string> non_terminals = new List<string>();

// Rules of the grammar
static Dictionary<string, List<List<string>>> R = new Dictionary<string, List<List<string>>>();

// function to perform the CYK Algorithm
static void cykParse(List<string> w)
{
    int n = w.Count;

    // Initialize the table
    SortedDictionary<int, SortedDictionary<int, SortedSet<string>>> T = new SortedDictionary<int, SortedDictionary<int, SortedSet<string>>>();

    // Filling in the table
    for (int j = 0 ; j < n ; j++)
    {

        // Iterate over the rules
        foreach (KeyValuePair<string, List<List<string>>> x in R)
        {
            string lhs = x.Key;
            List<List<string>> rule = x.Value;

            foreach (List<string> rhs in rule)
            {

                // If a terminal is found
                if(rhs.Count == 1 && rhs[0] == w[j]){
                    if(!T.ContainsKey(j)){
                        T.Add(j, new SortedDictionary<int, SortedSet<string>>());
                    }
                    if(!T[j].ContainsKey(j)){
                        T[j].Add(j, new SortedSet<string>());
                    }
                    T[j][j].Add(lhs);
                }
            }
        }
    }

    for(int i = j ; i >= 0 ; i--)
    {

        // Iterate over the range from i to j
        for(int k = i ; k <= j ; k++)
        {

            // Iterate over the rules
            foreach (KeyValuePair<string, List<List<string>>> x in R)
            {
                string lhs = x.Key;
                List<List<string>> rule = x.Value;
            }
        }
    }
}

```

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```

    {
        // If a terminal is found
        if(rhs.Count == 2 &&
            T.ContainsKey(i) &&
            T[i].ContainsKey(k) &&
            T[i][k].Contains(rhs[0]) &&
            T.ContainsKey(k + 1) &&
            T[k + 1].ContainsKey(j) &&
            T[k + 1][j].Contains(rhs[1]))
        {
            if(!T.ContainsKey(i)){
                T.Add(i, new SortedDictionary<int, SortedSet<string>>());
            }
            if(!T[i].ContainsKey(j)){
                T[i].Add(j, new SortedSet<string>());
            }
            T[i][j].Add(lhs);
        }
    }

    }
}

}

// If word can be formed by rules
// of given grammar
if(T.ContainsKey(0) && T[0].ContainsKey(n - 1) && T[0][n - 1].Count != 0){
    Console.WriteLine("True\n");
} else{
    Console.WriteLine("False\n");
}
}

// Driver code
public static void Main(string[] args){

    // terminal symbols
    // terminals = new List<string>{
    //     "book",
    //     "orange", "man",
    //     "tall", "heavy",
    //     "very", "muscular"
    // };

    // non terminal symbols
    // non_terminals = new List<string>{
    //     "NP", "Nom", "Det",
    //     "AP", "Adv", "A"
    // };
}

```

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```

        new List<string>{"Det", "Nom"}
    });

    R["Nom"] = new List<List<string>>{
        new List<string>{"AP", "Nom"},
        new List<string>{"book"},
        new List<string>{"orange"},
        new List<string>{"man"}
    };

    R["AP"] = new List<List<string>>{
        new List<string>{"Adv", "A"},
        new List<string>{"heavy"},
        new List<string>{"orange"},
        new List<string>{"tall"}
    };

    R["Det"] = new List<List<string>>{
        new List<string>{"a"}
    };

    R["Adv"] = new List<List<string>>{
        new List<string>{"very"},
        new List<string>{"extremely"}
    };

    R["A"] = new List<List<string>>{
        new List<string>{"heavy"},
        new List<string>{"orange"},
        new List<string> {"tall"},
        new List<string> {"muscular"}
    };

    // Given String
    List<string> w = new List<string> {"a", "very", "heavy", "orange", "book"};

    // Function Call
    cykParse(w);

}
}

// This code is contributed by subhamgoyal2014.

```

Javascript

```

// CYK Algorithm

// Non-terminal symbols

```

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```

// Rules of the grammar
const R = {
    "NP": [["Det", "Nom"]],
    "Nom": [[["AP", "Nom"], ["book"], ["orange"], ["man"]], [
        ["AP", "A"], ["heavy"], ["orange"], ["tall"]], [
            ["a"], [
                ["very"], ["extremely"]], [
                    ["heavy"], ["orange"], ["tall"], ["muscular"]]]]
};

// function to perform the CYK Algorithm
function cykParse(w) {
    let n = w.length;

    // Initialize the table
    let T = [];
    for (let i = 0; i < n; i++) {
        T[i] = [];
        for (let j = 0; j < n; j++) {
            T[i][j] = new Set();
        }
    }

    // Filling in the table
    for (let j = 0; j < n; j++) {
        // Iterate over the rules
        for (let lhs in R) {
            let rule = R[lhs];
            for (let rhs of rule) {
                // If a terminal is found
                if (rhs.length == 1 && rhs[0] == w[j]) {
                    T[j][j].add(lhs);
                }
            }
        }
        for (let i = j; i >= 0; i--) {
            // Iterate over the range from i to j
            for (let k = i; k <= j; k++) {
                // Iterate over the rules
                for (let lhs in R) {
                    let rule = R[lhs];
                    for (let rhs of rule) {
                        // If a terminal is found
                        if (rhs.length == 2 && T[i][k].has(rhs[0]) && T[k + 1][j].has(rhs[1])) {
                            T[i][j].add(lhs);
                        }
                    }
                }
            }
        }
    }
}

```

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```

}

// If word can be formed by rules
// of given grammar
if (T[0][n - 1].size !== 0) {
    console.log("True");
} else {
    console.log("False");
}
}

// Given String
const w = ["a", "very", "heavy", "orange", "book"];

// Function Call
cykParse(w);

```

Output:

True

Time Complexity: $O(N^3)$

Auxiliary Space: $O(N^2)$

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