MINISTERUL EDUCAȚIEI, CULTURII ȘI CERCETĂRII AL REPUBLICII MOLDOVA

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CEBAN VASILE FAF-223

Report

Laboratory work n.5

of Formal Languages and Finite Automata

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Topic: Chomsky Normal Form

Objectives:

1. Learn about Chomsky Normal Form (CNF) [1].
2. Get familiar with the approaches of normalizing a grammar.
3. Implement a method for normalizing an input grammar by the rules of CNF.
    a. The implementation needs to be encapsulated in a method with an appropriate signature (also ideally in an appropriate class/type).
    b. The implemented functionality needs executed and tested.
    c. A BONUS point will be given for the student who will have unit tests that validate the functionality of the project.
    d. Also, another BONUS point would be given if the student will make the aforementioned function to accept any grammar, not only the one from the student's variant.

Converting Context Free Grammar to Chomsky Normal Form

A context free grammar (CFG) is in Chomsky Normal Form (CNF) if all production rules satisfy one of the following conditions:

- A non-terminal generating a terminal (e.g.; X->x)
- A non-terminal generating two non-terminals (e.g.; X->YZ)
- Start symbol generating ε. (e.g.; S-> ε)

Consider the following grammars,

G1 = {S->a, S->AZ, A->a, Z->z}

G2 = {S->a, S->aZ, Z->a}

The grammar G1 is in CNF as production rules satisfy the rules specified for CNF. However, the grammar G2 is not in CNF as the production rule S->aZ contains terminal followed by non-terminal which does not satisfy the rules specified for CNF.

Note –

- For a given grammar, there can be more than one CNF.
- CNF produces the same language as generated by CFG.

- CNF is used as a preprocessing step for many algorithms for CFG like CYK(membership algo), bottom-up parsers etc.
- For generating string w of length ‘n’ requires ‘2n-1’ production or steps in CNF.
- Any Context free Grammar that do not have ε in it’s language has an equivalent CNF.

Source Code:

```
    for (Map.Entry<String, List<String>> entry : updatedRules.entrySet()) {
        String fromState = entry.getKey();
        List<String> toStates = entry.getValue();
        List<String> newToStates = new ArrayList<>();
        for (String production : toStates) {
            if (production.length() > 2) {
                String newNonTerminal = nonTerminalMapping.get(production);
                if (newNonTerminal == null) {
                    newNonTerminal =
generateNewNonTerminal(newNonTerminalsMap, newNonTerminalCounter++,
production);
                    newNonTerminalsMap.put(newNonTerminal,
production.substring(1));
                    nonTerminalMapping.put(production, newNonTerminal);
                }
                newToStates.add(production.charAt(0) + newNonTerminal);
            } else {
                newToStates.add(production);
            }
        }
        updatedRules.put(fromState, newToStates);
    }

    for (Map.Entry<String, String> entry : newNonTerminalsMap.entrySet()) {
        updatedRules.put(entry.getKey(), List.of(entry.getValue()));
    }

    for (Map.Entry<String, List<String>> entry : updatedRules.entrySet()) {
        String fromState = entry.getKey();
        List<String> toStates = entry.getValue();
        List<String> newToStates = new ArrayList<>();
        for (String production : toStates) {
            if (production.length() == 2 &&
Character.isLowerCase(production.charAt(0)) &&
Character.isUpperCase(production.charAt(1))) {
                String terminal = production.substring(0, 1);
                String nonTerminal =
terminalNonTerminalsMap.getOrDefault(terminal, null);
                if (nonTerminal == null) {
```

```
                    nonTerminal = generateNewNonTerminal(newNonTerminalsMap,
newNonTerminalCounter++, terminal);
                    terminalNonTerminalsMap.put(terminal, nonTerminal);
                }
                newToStates.add(nonTerminal + production.charAt(1));
            } else {
                newToStates.add(production);
            }
        }
        updatedRules.put(fromState, newToStates);
    }

    for (Map.Entry<String, String> entry : newNonTerminalsMap.entrySet()) {
        String nonTerminal = entry.getKey();
        String terminal = entry.getValue();
        updatedRules.put(nonTerminal, List.of(terminal));
    }

    setRules(updatedRules);
}
```

Description:

1. First Loop:
    - It goes through each state and its associated list of productions.
    - If a production is longer than 2 characters, it checks if there's a mapping for its non-terminal part.
    - If not, it generates a new non-terminal symbol, updates the mapping, and replaces the non-terminal part in the production with the new symbol.
2. Second Loop:
    - It goes through newly created non-terminal symbols and their associated productions.
    - It updates the rules with these new non-terminal productions.
3. Third Loop:
    - It goes through each state again.
    - If a production consists of a lowercase terminal followed by an uppercase non-terminal, it replaces the terminal with a corresponding non-terminal symbol.
4. Fourth Loop:
    - It goes through the mappings of new non-terminal symbols to terminals.
    - It updates the rules with these mappings.
5. Conclusion:
    - Finally, it updates the rules with the modifications made during the loops.

```
   do {
       changed = false;
        for (Map.Entry<String, List<String>> entry : updatedRules.entrySet())
{
           String fromState = entry.getKey();
           List<String> toStates = entry.getValue();
           List<String> newToStates = new ArrayList<>();
           for (String production : toStates) {
                                        if (production.length() == 1 &&
Character.isUpperCase(production.charAt(0))) {
                                            List<String> unitProductions =
updatedRules.get(production);
                   if (unitProductions != null) {
                       newToStates.addAll(unitProductions);
                       changed = true;
                   }
               } else {
                   newToStates.add(production);
               }
           }
           updatedRules.put(fromState, newToStates);
       }

        for (Map.Entry<String, List<String>> entry : updatedRules.entrySet())
{
           String fromState = entry.getKey();
           List<String> toStates = entry.getValue();
           List<String> newToStates = new ArrayList<>();
           for (String production : toStates) {
                                       if (!(production.length() == 1 &&
Character.isUpperCase(production.charAt(0)))) {
                   newToStates.add(production);
               }
           }
           updatedRules.put(fromState, newToStates);
       }
   } while (changed);
   setRules(updatedRules);
}
```

Description:
This method removes unit productions from the grammar. It iteratively removes unit productions by replacing them with their corresponding productions until no more unit productions remain.

1. Initialization:
    - It initializes a HashMap named updatedRules by copying the content of another map, possibly obtained from getRules() method.
2. Main Loop:

- It enters a do-while loop. The loop continues until there are no changes made in the current iteration (changed remains false).
- The loop iterates over each entry in updatedRules.
- For each state (fromState), it goes through its list of productions (toStates).
- If a production consists of only one uppercase letter, it's considered a unit production.
    - It checks if there's a list of productions associated with this unit production in the map.
    - If such productions exist, it adds them to newToStates and sets changed to true.
    - If not, it adds the original production to newToStates.
- After processing all productions for a state, it updates updatedRules with newToStates.

3. Second Loop:
    - After the first loop, it goes through each entry in updatedRules again.
    - This time, for each state, it removes all unit productions (productions consisting of only one uppercase letter) from its list of productions.
    - It constructs a new list newToStates excluding unit productions and updates updatedRules with it.
4. Continuation:
    - The loop continues until no changes are made in an iteration, indicating that all unit productions have been eliminated.
5. Setting Updated Rules:
    - Once the loop completes, it sets the rules with the updated rules using the setRules method.

```
private String generateNewNonTerminal(Map<String, String> newNonTerminals, int
counter, String symbols) {
 return newNonTerminal;
}
```

Description:

This method generates a new non-terminal symbol for use in the conversion process. It ensures that each new non-terminal has a unique identifier and returns the generated non-terminal.

```
Set<String> epsilonStates = new HashSet<>();
for (Map.Entry<String, List<String>> entry : updatedRules.entrySet()) {
    if (entry.getValue().contains("")) {
        epsilonStates.add(entry.getKey());
    }
}

for (String state : epsilonStates) {
    List<String> productions = updatedRules.get(state);
    List<String> updatedProductions = new ArrayList<>(productions);
```

```
        updatedProductions.remove("");
        updatedRules.put(state, updatedProductions);
    }

    for (String stateWithEpsilon : epsilonStates) {
         for (Map.Entry<String, List<String>> entry : updatedRules.entrySet())
{
            String fromState = entry.getKey();
            List<String> toStates = entry.getValue();
            List<String> newToStates = new ArrayList<>();
            for (String production : toStates) {
                if (production.contains(stateWithEpsilon)) {
                                        List<String>  replicatedProductions  =
replicateProduction(production, stateWithEpsilon);
                    newToStates.addAll(replicatedProductions);
                } else {
                    newToStates.add(production);
                }
            }
            updatedRules.put(fromState, newToStates);
        }
    }

    for (Map.Entry<String, List<String>> entry : updatedRules.entrySet()) {
        String fromState = entry.getKey();
        List<String> toStates = entry.getValue();
        Set<String> uniqueToStates = new HashSet<>();
        for (String production : toStates) {
            generateCombinations("", production, 0, uniqueToStates);
        }
        updatedRules.put(fromState, new ArrayList<>(uniqueToStates));
    }

    setRules(updatedRules);
}
```

Description:

This method removes epsilon (empty string) productions from the grammar. It identifies states with epsilon productions and removes them from the grammar rules. Then, it replicates productions containing states with epsilon productions to account for their absence and generates all possible combinations of productions.

1. Identifying Epsilon States:
    - It looks for states with epsilon productions and stores them in epsilonStates.
2. Removing Epsilon Productions:
    - It removes epsilon productions from states in epsilonStates.
3. Expanding Epsilon Productions:
    - It expands epsilon productions in other states by replacing occurrences of epsilon-producing states with empty strings.
4. Generating Combinations:

- It generates all possible combinations of productions for each state, ensuring uniqueness.

5. Setting Updated Rules:
    - It updates the rules with the modifications.

```
    List<String> replicatedProductions = new ArrayList<>();
        int numInstances = (int) production.chars().filter(ch -> ch ==
stateWithEpsilon.charAt(0)).count();
    for (int i = 0; i < Math.pow(2, numInstances); i++) {
        StringBuilder sb = new StringBuilder(production);
        for (int j = 0; j < numInstances; j++) {
            if ((i & (1 << j)) != 0) {
                int index = sb.indexOf(stateWithEpsilon);
                sb.replace(index, index + 1, "");
            }
        }
        replicatedProductions.add(sb.toString());
    }
    return replicatedProductions;
}
```

Description:

This method replicates productions containing states with epsilon productions to account for their absence. It generates all possible combinations of productions by replacing epsilon symbols with empty strings and returns the replicated productions.

1. Initialization:
    - It initializes an empty list replicatedProductions to store the generated productions.
    - It calculates the number of occurrences of stateWithEpsilon in the production string using numInstances.
2. Generating Combinations:
    - It iterates from i = 0 to 2^numInstances - 1. This loop generates all possible combinations by treating each bit of i as a switch to indicate whether to remove the corresponding occurrence of stateWithEpsilon.
    - For each value of i, it creates a copy of the original production string using a StringBuilder.
    - It then iterates through each bit of i (indexed by j). If the j-th bit of i is set (1), it finds the index of the next occurrence of stateWithEpsilon in the StringBuilder and removes it by replacing it with an empty string.
    - After each iteration, it adds the modified production string to the replicatedProductions list.
3. Return:
    - After generating all possible combinations, it returns the list of replicated productions.

Conclusion

In this laboratory work, we aimed to delve into the concept of Chomsky Normal Form (CNF) and explore the methods for normalizing a grammar according to CNF rules. The primary objectives included gaining an understanding of CNF, implementing a method to normalize an input grammar, and testing the functionality of the implementation.

Throughout the process, we learned about the importance of CNF in formal language theory and its significance in various computational tasks, such as parsing and manipulation of context-free grammars. By dissecting the steps required to convert a grammar into CNF, we gained insights into grammar manipulation techniques crucial for language processing tasks.

The implementation involved encapsulating the normalization functionality within a method and structuring it appropriately within a class. We ensured the versatility of the method by designing it to accept any grammar, not limited to a specific variant. This adaptability enhances the utility of the implementation, making it applicable to a wide range of grammatical structures.

Furthermore, we emphasized the significance of testing the implemented functionality. Unit tests were employed to validate the correctness and robustness of the normalization process, ensuring that the converted grammars adhere to the CNF rules consistently across different inputs.

In conclusion, this laboratory work provided a hands-on experience in understanding and implementing CNF normalization techniques, reinforcing fundamental concepts in formal language theory and computational linguistics. The acquired knowledge and practical skills lay a solid foundation for tackling more advanced language processing tasks and exploring further areas in theoretical computer science.