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[Knowledge is Nectar]

Department of Computer Engineering

Course - System Programming and Compiler Construction (SPCC)

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Class and Batch	TE Computer Engineering - Batch __
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Aim	Write a program to implement optimization of DFA-Based Pattern Matchers
Objective	To build a parse tree To find firstpos To find lastpos To find followpos To build DFA
Theory	**Parsing and Automata:** In the world of programming languages, parsing plays a crucial role in understanding the structure and meaning of code. Let's delve into some key concepts involved in this process: **Building a Parse Tree:** A parse tree, often resembling an upside-down tree, is a graphical representation of a program's grammatical structure [1]. It depicts how tokens (the basic building blocks of code) are combined to form expressions and statements, reflecting the language's syntax. Here's the process of building a parse tree: **Start with the initial symbol:** This represents the entire program and is often denoted by "S" or the grammar's starting point. **Match tokens:** Use production rules from the grammar to match the first token against the left-hand side of a rule. If there's a match, replace it with the right-hand side. **Repeat:** Recursively apply step 2 for each newly exposed non-terminal symbol (a symbol representing a group of rules), continuing until all tokens are consumed and a terminal symbol (representing a single token) remains at each leaf node. **Finding Firstpos:** Firstpos, short for "first position sets," is a crucial concept in LL parsing [2]. It defines the set of terminal symbols that can begin any valid sentence derived from a non-terminal symbol. To find firstpos:

For each non-terminal:

- Check if it directly expands to a terminal symbol. If so, add that symbol to its firstpos set.
- Iterate through each production rule for the non-terminal.
- For each rule:
  - Find the firstpos of the first symbol on the right-hand side.
  - If "ε" (empty string) is in the firstpos and the symbol is nullable (can be replaced by ε), add all symbols after it to the current non-terminal's firstpos.
  - Continue until encountering a non-nullable symbol or reaching the end of the rule.

Finding Lastpos:
Lastpos, or "last position sets," are analogous to firstpos but refer to the set of terminal symbols that can end a valid sentence derived from a non-terminal [2]. To find lastpos:

For each non-terminal:

- Reverse each production rule for the non-terminal.
- Find the firstpos of the reversed rule (now acting as the beginning).
- Remove "ε" from the resulting set.

Finding Followpos:
Followpos, or "follow sets," are crucial in both LL and LR parsing [2]. They define the set of terminal symbols that can follow a specific non-terminal in a valid sentence. To find followpos:

For each non-terminal:

- Add the end-of-input symbol ($) to its followpos if it can appear at the end of a sentence.
- For each production rule where the non-terminal appears:
  - Find the firstpos of the symbols following the non-terminal in the rule.
  - Remove "ε" from the resulting set.
  - If "ε" is in the firstpos and the symbol following the non-terminal is nullable, add the followpos of the non-terminal itself to the current set.

Building a Deterministic Finite Automaton (DFA):

A DFA is a powerful tool for recognizing regular languages [3]. It comprises states, transitions between states, and an initial and final state. To build a DFA:

- Start with the initial state.
- For each state:
  - For each symbol in the alphabet:
    - Create a new state or use an existing one.
    - Add a transition labeled with the symbol from the current state to the new/existing state.
  - Mark the final state(s) based on the language's definition.

	Remember, these are just foundational concepts. Each topic deserves deeper exploration, and many resources are available to delve further.
Implementation / Code	

```java
import java.util.*;

class Node {
    char value;
    Node leftc;
    Node rightc;
    int posNumber;
    Set<Integer> firstpos;
    Set<Integer> lastpos;
    Set<Integer> followpos;
    boolean nullable;

    Node(char value) {
        this.value = value;
        firstpos = new HashSet<Integer>();
        lastpos = new HashSet<Integer>();
        followpos = new HashSet<Integer>();
        posNumber = 0;
    }
}

class State {
    ArrayList<Integer> value;
    boolean marked;

    State() {
        value = new ArrayList<Integer>();
    }

}

class Transition {
    State from;
```

```
    State to;
    char value;

    Transition(State from, State to, char value) {
        this.from = from;
        this.to = to;
        this.value = value;
    }

}

class Tree {
    Node root;
    int count = 0;
    Set<Character> alphabet;
    ArrayList<Node> leaves;
    ArrayList<State> Dstates;
    ArrayList<Transition> Dtrans;

    Tree() {
        root = null;
        leaves = new ArrayList<Node>();
        alphabet = new HashSet<Character>();
        Dstates = new ArrayList<State>();
        Dtrans = new ArrayList<Transition>();
    }

    void parseRegex(String regex) {
        Stack<Character> st = new Stack<>();
        for (int i = 0; i < regex.length(); i++) {
            if (regex.charAt(i) == '(') {
                int j = i + 1;
                while (regex.charAt(j) != ')') {
                    st.push(regex.charAt(j));
                    if (Character.isLetter(regex.charAt(j))) {
                        count++;
```

```
                    alphabet.add(regex.charAt(j));
                }
                j++;
            }
            j++;
            char c1 = st.pop();
            char c2 = st.pop();
            char c3 = st.pop();
            Node n1 = new Node(c1);
            Node n2 = new Node(c2);
            Node n3 = new Node(c3);
            n2.leftc = n3;
            n2.rightc = n1;
            i = j;
            root = n2;

        }
        if (regex.charAt(i) == '*') {
            Node temp = new Node('*');
            temp.leftc = root;
            root = temp;
        }
        if (Character.isLetter(regex.charAt(i))) {
            count++;
            alphabet.add(regex.charAt(i));
            if (root != null) {
                if (root.value != '.') {
                    Node temp = new Node('.');
                    temp.leftc = root;
                    temp.rightc = new Node(regex.charAt(i));
                    root = temp;
                } else {
                    if (root.rightc != null) {
                        Node temp = new Node('.');
                        temp.leftc = root;
                        temp.rightc = new Node(regex.charAt(i));
```

```
                            root = temp;
                        } else {
                            root.rightc = new Node(regex.charAt(i));
                        }
                    }
                } else {
                    Node temp = new Node('.');
                    temp.leftc = new Node(regex.charAt(i));
                }
            }
        }
        Node temp = new Node('.');
        temp.rightc = new Node('#');
        temp.leftc = root;
        root = temp;
        count++;
    }

   void printTree() {

System.out.println("-----------------------------------------------------
-----------------------------------------");
    System.out.printf("| %-5s | %-14s | %-15s | %-9s | %-12s | %-8s |
%-12s |\n",
                      "Value", "Left Child", "Right Child",
"Nullable", "Firstpos", "Lastpos", "Followpos");

System.out.println("-----------------------------------------------------
-----------------------------------------");
    printTree(root);

System.out.println("-----------------------------------------------------
-----------------------------------------");
}

void printTree(Node n) {
```

```
    if (n == null) {
        return;
    }
    System.out.printf("| %-5s | %-14s | %-15s | %-9s | %-12s | %-8s |
%-12s |\n",
                      n.value, (n.leftc != null) ? n.leftc.value :
"null",
                      (n.rightc != null) ? n.rightc.value : "null",
n.nullable,
                      n.firstpos, n.lastpos, n.followpos);
    printTree(n.leftc);
    printTree(n.rightc);
}


    void numberLeaves(Node n) {
        if (isLeaf(n)) {
            n.posNumber = count;
            n.firstpos.add(count);
            n.lastpos.add(count);
            leaves.add(0, n);
            count--;
            return;
        } else if (n.value == '*') {
            numberLeaves(n.leftc);
        } else {
            numberLeaves(n.rightc);
            numberLeaves(n.leftc);
        }
    }

    void assignNullable(Node n) {
        if (n.value == '|') {
            n.nullable = n.leftc.nullable || n.rightc.nullable;
            assignNullable(n.leftc);
            assignNullable(n.rightc);
```

```
        } else if (n.value == '.') {
            n.nullable = n.leftc.nullable && n.rightc.nullable;
            assignNullable(n.leftc);
            assignNullable(n.rightc);
        } else if (n.value == '*') {
            n.nullable = true;
            assignNullable(n.leftc);
        } else {
            n.nullable = false;
        }
    }

    void assignFirstLastPos(Node n) {
        if (n.value == '|') {
            assignFirstLastPos(n.leftc);
            assignFirstLastPos(n.rightc);

            Set<Integer> temp1 = new HashSet<Integer>();
            temp1.addAll(n.leftc.firstpos);
            temp1.addAll(n.rightc.firstpos);
            n.firstpos.addAll(temp1);

            Set<Integer> temp2 = new HashSet<Integer>();
            temp2.addAll(n.leftc.lastpos);
            temp2.addAll(n.rightc.lastpos);
            n.lastpos.addAll(temp2);

        } else if (n.value == '.') {
            assignFirstLastPos(n.leftc);
            assignFirstLastPos(n.rightc);
            if (n.leftc.nullable) {
                Set<Integer> temp1 = new HashSet<Integer>();
                temp1.addAll(n.leftc.firstpos);
                temp1.addAll(n.rightc.firstpos);
                n.firstpos.addAll(temp1);
            } else {
```

```
                n.firstpos.addAll(n.leftc.firstpos);
            }

            if (n.rightc.nullable) {
                Set<Integer> temp1 = new HashSet<Integer>();
                temp1.addAll(n.leftc.lastpos);
                temp1.addAll(n.rightc.lastpos);
                n.lastpos.addAll(temp1);
            } else {
                n.lastpos.addAll(n.rightc.lastpos);
            }
        } else if (n.value == '*') {
            assignFirstLastPos(n.leftc);
            n.firstpos.addAll(n.leftc.firstpos);
            n.lastpos.addAll(n.leftc.lastpos);
        } else {
            return;
        }
    }

    void calculateFollowPos(Node n) {
        if (n.value == '.') {
            Iterator<Integer> it = n.leftc.lastpos.iterator();
            while (it.hasNext()) {
                int i = it.next();
                Set<Integer> temp = new HashSet<Integer>();
                temp.addAll(n.rightc.firstpos);
                temp.addAll(leaves.get(i - 1).followpos);
                leaves.get(i - 1).followpos.addAll(temp);
            }
        } else if (n.value == '*') {
            Iterator<Integer> it = n.lastpos.iterator();
            while (it.hasNext()) {
                int i = it.next();
                Set<Integer> temp = new HashSet<Integer>();
                temp.addAll(n.firstpos);
```

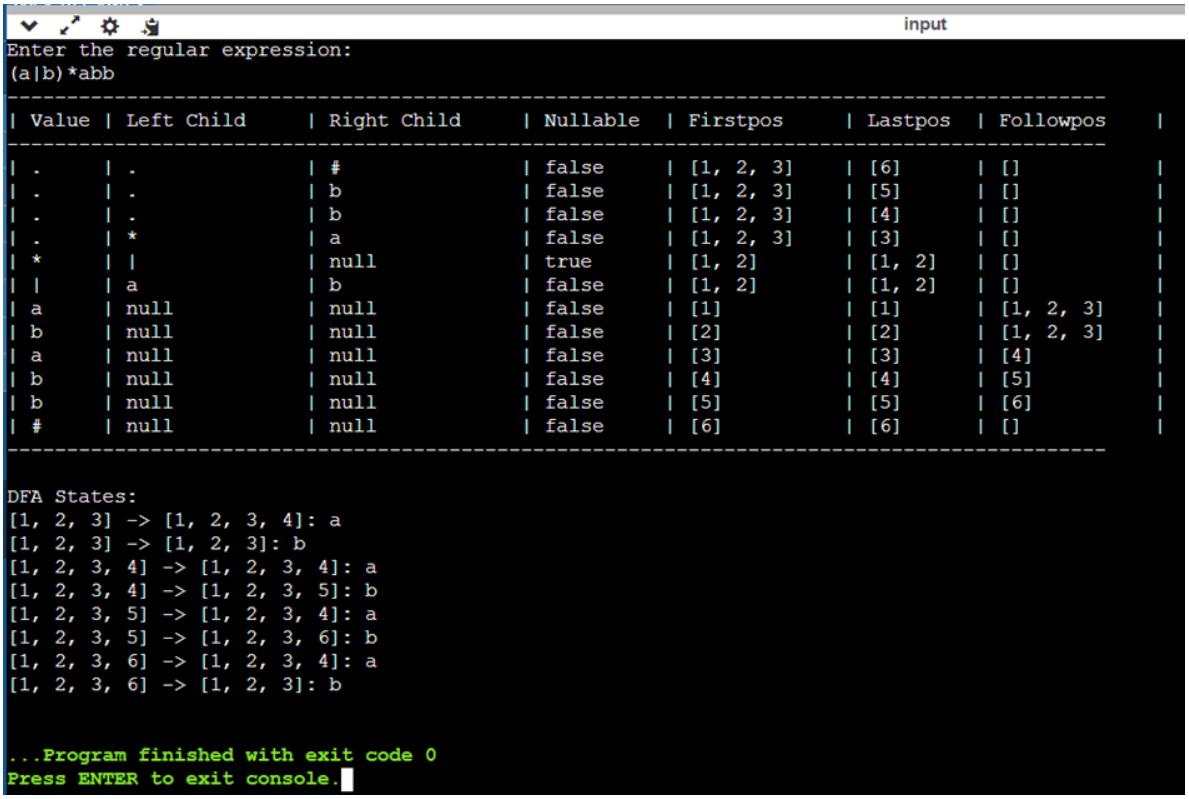
```
                temp.addAll(leaves.get(i - 1).followpos);
                leaves.get(i - 1).followpos.addAll(temp);
            }
        }
    }

    void assignFollowPos(Node n) {
        if (n == null) {
            return;
        } else {
            calculateFollowPos(n);
            assignFollowPos(n.leftc);
            assignFollowPos(n.rightc);
        }
    }

    void constructDstates() { State s0 = new State();
        s0.value.addAll(root.firstpos); Dstates.add(s0);

        Queue<State> queue = new LinkedList<>(); queue.add(s0);

// Set to keep track of processed states
        Set<Set<Integer>> processedStates = new HashSet<>();

        processedStates.add(new HashSet<>(s0.value)); // Convert
ArrayList<Integer> to Set<Integer>

        while (!queue.isEmpty()) {
            State currentState = queue.poll();

            for (char a : alphabet) { Set<Integer> U = new
HashSet<>();
                for (int p : currentState.value) { Node node =
leaves.get(p - 1); if (node.value == a) {
                    U.addAll(node.followpos);
                }
```

```
                }

                if (!processedStates.contains(U)) {
                    State newState = new State();
                    newState.value.addAll(U);
                    Dstates.add(newState);
                    queue.add(newState);
                    processedStates.add(U);
                }

                State newState = getStateByValue(Dstates, U);
                Dtrans.add(new Transition(currentState, newState, a));
            }
        }
    }

    void printDFA(){
        System.out.println('\n' + "DFA States: "); for (Transition t :
Dtrans) {
            System.out.println(t.from.value + " -> " + t.to.value + ":
" + t.value);
        }
    }

    boolean containsState(ArrayList<State> states, Set<Integer> value)
{
        for (State state : states) {
            if (state.value.equals(value)) {
                return true;
            }
        }
        return false;
    }

    State getStateByValue(ArrayList<State> states, Set<Integer> value)
    {
```

```
        for (State state : states) {
            if (state.value.size() != value.size()) {
                continue; // If sizes are different, sets cannot be
equal
            }

            boolean equalSets = true;
            for (int pos : state.value) { if (!value.contains(pos)) {
                equalSets = false; break;
            }
            }

            if (equalSets) { return state;
            }
        }
        return null;
    }

    boolean isLeaf(Node n) {
        return n.leftc == null && n.rightc == null;
    }

    State getUnmarkedState() {
        for (int i = 0; i < Dstates.size(); i++) {
            if (!Dstates.get(i).marked) {
                return Dstates.get(i);
            }
        }
        return null;
    }

    boolean checkAllMarked() {
        for (int i = 0; i < Dstates.size(); i++) {
            if (!Dstates.get(i).marked) {
                return false;
            }
```

```
        }
        return true;
    }
}

public class parseTree {
    public static void main(String args[]) {
        Tree t = new Tree();
        Scanner sc = new Scanner(System.in);
        System.out.println("Enter the regular expression: ");
        String regex = sc.nextLine();
        t.parseRegex(regex);
        t.numberLeaves(t.root);
        t.assignNullable(t.root);
        t.assignFirstLastPos(t.root);
        t.assignFollowPos(t.root);
        t.constructDstates();
        t.printTree();
        t.printDFA();
        sc.close();
    }
}
```

Output



Conclusion

In summary, our experiment focused on enhancing DFA-Based Pattern Matchers. We achieved our goal by creating a parse tree from the given pattern, calculating firstpos, lastpos, and followpos sets, and proficiently constructing a Deterministic Finite Automaton (DFA). This approach significantly improved the efficiency of pattern matching in our study.

References

References:

[1] Aho, A. V., Sethi, R., & Ullman, J. D. (2007). Compilers: principles, techniques, and tools (2nd ed.). Addison-Wesley.
[2] Appel, A. W. (2014). Modern compiler implementation in Java. Cambridge University Press.
[3] Hopcroft, J. E., Motwani, R., & Ullman, J. D. (2001). Introduction to automata theory, languages, and computation (2nd ed.). Addison-Wesley.