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Experiment No.	1

Aim

Experiment 1: Optimization of DFA

Input: Regular Expression

Output: **for each node** print nullable , firstpos , lastpos , followpos

```
            print state transition table of DFA
            State name |    Symbol 1  | Symbol 2   |
           ____________________________________
          |          |              |           |
          _____________________________________
          |          |              |            |
          ______________________________________
```

Code:

```c
#include <stdio.h>
#include <stdlib.h>
#include <stdbool.h>
#include <string.h>

// Define initial capacities
#define INITIAL_CAPACITY 10
#define MAX_ALPHABET_SIZE 256

// Struct for dynamic integer set
typedef struct IntSet {
    int *elements;
    int size;
    int capacity;
} IntSet;

// Initialize IntSet
void initIntSet(IntSet *set) {
    set->elements = (int *)malloc(INITIAL_CAPACITY * sizeof(int));
    set->size = 0;
    set->capacity = INITIAL_CAPACITY;
}

// Add element to IntSet if not present
void addToIntSet(IntSet *set, int value) {
    for(int i = 0; i < set->size; i++) {
        if(set->elements[i] == value)
            return;
    }
    if(set->size == set->capacity) {
        set->capacity *= 2;
        set->elements = (int *)realloc(set->elements, set->capacity * sizeof(int));
    }
    set->elements[set->size++] = value;
}

// Check if IntSet contains a value
bool containsIntSet(IntSet *set, int value) {
    for(int i = 0; i < set->size; i++) {
        if(set->elements[i] == value)
            return true;
    }
    return false;
}

// Struct for dynamic list of integers
typedef struct IntList {
    int *items;
    int size;
    int capacity;
} IntList;

// Initialize IntList
void initIntList(IntList *list) {
    list->items = (int *)malloc(INITIAL_CAPACITY * sizeof(int));
    list->size = 0;
    list->capacity = INITIAL_CAPACITY;
}

// Add item to IntList
void addToIntList(IntList *list, int value) {
    if(list->size == list->capacity) {
        list->capacity *= 2;
        list->items = (int *)realloc(list->items, list->capacity * sizeof(int));
    }
    list->items[list->size++] = value;
}

// Struct for Node
typedef struct Node {
    char value;
    struct Node *leftc;
    struct Node *rightc;
    int posNumber;
    IntSet firstpos;
    IntSet lastpos;
    IntSet followpos;
    bool nullable;
} Node;

// Initialize Node
Node* createNode(char value) {
    Node *node = (Node *)malloc(sizeof(Node));
    node->value = value;
    node->leftc = NULL;
    node->rightc = NULL;
    node->posNumber = 0;
    initIntSet(&(node->firstpos));
    initIntSet(&(node->lastpos));
    initIntSet(&(node->followpos));
    node->nullable = false;
    return node;
```

```
}

// Struct for State
typedef struct State {
    IntList value;
    bool marked;
} State;

// Initialize State
State* createState() {
    State *state = (State *)malloc(sizeof(State));
    initIntList(&(state->value));
    state->marked = false;
    return state;
}

// Struct for Transition
typedef struct Transition {
    State *from;
    State *to;
    char value;
} Transition;

// Struct for dynamic list of Nodes
typedef struct NodeList {
    Node **items;
    int size;
    int capacity;
} NodeList;

// Initialize NodeList
void initNodeList(NodeList *list) {
    list->items = (Node **)malloc(INITIAL_CAPACITY * sizeof(Node *));
    list->size = 0;
    list->capacity = INITIAL_CAPACITY;
}
```

```
// Add Node to NodeList
void addToNodeList(NodeList *list, Node *node) {
    if(list->size == list->capacity) {
        list->capacity *= 2;
        list->items = (Node **)realloc(list->items, list->capacity * sizeof(Node *));
    }
    list->items[list->size++] = node;
}

// Struct for dynamic list of States
typedef struct StateList {
    State **items;
    int size;
    int capacity;
} StateList;

// Initialize StateList
void initStateList(StateList *list) {
    list->items = (State **)malloc(INITIAL_CAPACITY * sizeof(State *));
    list->size = 0;
    list->capacity = INITIAL_CAPACITY;
}

// Add State to StateList
void addToStateList(StateList *list, State *state) {
    if(list->size == list->capacity) {
        list->capacity *= 2;
        list->items = (State **)realloc(list->items, list->capacity * sizeof(State *));
    }
    list->items[list->size++] = state;
}

// Struct for dynamic list of Transitions
typedef struct TransitionList {
    Transition **items;
    int size;
    int capacity;
```

```
} TransitionList;

// Initialize TransitionList
void initTransitionList(TransitionList *list) {
    list->items = (Transition **)malloc(INITIAL_CAPACITY * sizeof(Transition *));
    list->size = 0;
    list->capacity = INITIAL_CAPACITY;
}

// Add Transition to TransitionList
void addToTransitionList(TransitionList *list, Transition *trans) {
    if(list->size == list->capacity) {
        list->capacity *= 2;
        list->items = (Transition **)realloc(list->items, list->capacity * sizeof(Transition *));
    }
    list->items[list->size++] = trans;
}

// Struct for Queue of State pointers
typedef struct QueueNode {
    State *state;
    struct QueueNode *next;
} QueueNode;

typedef struct Queue {
    QueueNode *front;
    QueueNode *rear;
} Queue;

// Initialize Queue
void initQueue(Queue *q) {
    q->front = q->rear = NULL;
}

// Enqueue State
void enqueue(Queue *q, State *state) {
    QueueNode *temp = (QueueNode *)malloc(sizeof(QueueNode));
    temp->state = state;
    temp->next = NULL;
    if(q->rear == NULL) {
        q->front = q->rear = temp;
        return;
    }
    q->rear->next = temp;
    q->rear = temp;
}

// Dequeue State
State* dequeue(Queue *q) {
    if(q->front == NULL)
        return NULL;
    QueueNode *temp = q->front;
    State *state = temp->state;
    q->front = q->front->next;
    if(q->front == NULL)
        q->rear = NULL;
    free(temp);
    return state;
}

// Check if Queue is empty
bool isQueueEmpty(Queue *q) {
    return q->front == NULL;
}

// Struct for Tree
typedef struct Tree {
    Node *root;
    int count;
    bool alphabet[MAX_ALPHABET_SIZE];
    NodeList leaves;
    StateList Dstates;
    TransitionList Dtrans;
} Tree;
```

```
// Initialize NodeList, StateList, TransitionList in Tree
void initTree(Tree *tree) {
    tree->root = NULL;
    tree->count = 0;
    for(int i = 0; i < MAX_ALPHABET_SIZE; i++)
        tree->alphabet[i] = false;
    initNodeList(&(tree->leaves));
    initStateList(&(tree->Dstates));
    initTransitionList(&(tree->Dtrans));
}

// Function to check if character is a letter
bool isLetter(char c) {
    return (c >= 'a' && c <= 'z') || (c >= 'A' && c <= 'Z');
}

// Function to parse regex
void parseRegex(Tree *tree, char *regex) {
    // Implement a simple stack using dynamic array
    int stackCapacity = INITIAL_CAPACITY;
    char *stack = (char *)malloc(stackCapacity * sizeof(char));
    int top = -1;

    int i = 0;
    while(i < strlen(regex)) {
        char current = regex[i];
        if(current == '(') {
            i++;
            while(regex[i] != ')' && i < strlen(regex)) {
                if(top == stackCapacity -1) {
                    stackCapacity *=2;
                    stack = (char *)realloc(stack, stackCapacity * sizeof(char));
                }
                stack[++top] = regex[i];
                if(isLetter(regex[i])) {
                    tree->count++;
                    tree->alphabet[(int)regex[i]] = true;
                }
                i++;
            }
            // Pop three characters
            if(top >=2) {
                char c1 = stack[top--];
                char c2 = stack[top--];
                char c3 = stack[top--];
                Node *n1 = createNode(c1);
                Node *n2 = createNode(c2);
                Node *n3 = createNode(c3);
                n2->leftc = n3;
                n2->rightc = n1;
                tree->root = n2;
            }
            i++;
        }
        else if(current == '*') {
            Node *temp = createNode('*');
            temp->leftc = tree->root;
            tree->root = temp;
            i++;
        }
        else if(isLetter(current)) {
            tree->count++;
            tree->alphabet[(int)current] = true;
            if(tree->root != NULL) {
                if(tree->root->value != '.') {
                    Node *temp = createNode('.');
                    temp->leftc = tree->root;
                    temp->rightc = createNode(current);
                    tree->root = temp;
                }
                else {
                    if(tree->root->rightc != NULL) {
                        Node *temp = createNode('.');
```

```
                        temp->leftc = tree->root;
                        temp->rightc = createNode(current);
                        tree->root = temp;
                    }
                    else {
                        tree->root->rightc = createNode(current);
                    }
                }
            }
            else {
                Node *temp = createNode('.');
                temp->leftc = createNode(current);
                tree->root = temp;
            }
            i++;
        }
        else {
            i++;
        }
    }
    // Append '.' and '#' to the tree
    Node *temp = createNode('.');
    temp->rightc = createNode('#');
    temp->leftc = tree->root;
    tree->root = temp;
    tree->count++;
    free(stack);
}

// Function to print Tree
void printTreeHelper(Node *n) {
    if(n == NULL)
        return;
    printf("%-6c | %-12s | %-12s | %-8s | ", n->value,
        n->leftc != NULL ? (char[]){n->leftc->value, '\0'} : "null",
        n->rightc != NULL ? (char[]){n->rightc->value, '\0'} : "null",
        n->nullable ? "true" : "false");
    printf("{");
    for(int i = 0; i < n->firstpos.size; i++) {
        printf("%d", n->firstpos.elements[i]);
        if(i < n->firstpos.size -1) printf(", ");
    }
    printf("} | {");
    for(int i = 0; i < n->lastpos.size; i++) {
        printf("%d", n->lastpos.elements[i]);
        if(i < n->lastpos.size -1) printf(", ");
    }
    printf("} | {");
    for(int i = 0; i < n->followpos.size; i++) {
        printf("%d", n->followpos.elements[i]);
        if(i < n->followpos.size -1) printf(", ");
    }
    printf("}\n");
    printTreeHelper(n->leftc);
    printTreeHelper(n->rightc);
}

void printTree(Tree *tree) {
    printf("%-6s | %-12s | %-12s | %-8s | %-10s | %-9s | %-11s\n",
        "Value", "Left Child", "Right Child", "Nullable", "Firstpos", "Lastpos", "Followpos");
    printTreeHelper(tree->root);
}

// Function to check if Node is leaf
bool isLeaf(Node *n) {
    return n->leftc == NULL && n->rightc == NULL;
}

// Function to add Node to leaves
void addToLeaves(Tree *tree, Node *n) {
    // Insert at beginning
    if(tree->leaves.size == tree->leaves.capacity) {
        tree->leaves.capacity *=2;
        tree->leaves.items = (Node **)realloc(tree->leaves.items, tree->leaves.capacity * sizeof(Node *));
    }
    for(int i = tree->leaves.size; i >0; i--) {
        tree->leaves.items[i] = tree->leaves.items[i-1];
    }
    tree->leaves.items[0] = n;
    tree->leaves.size++;
}

// Function to number leaves
void numberLeaves(Tree *tree, Node *n) {
    if(isLeaf(n)) {
        n->posNumber = tree->count;
        addToIntSet(&(n->firstpos), tree->count);
        addToIntSet(&(n->lastpos), tree->count);
        addToLeaves(tree, n);
        tree->count--;
        return;
    }
    if(n->value == '*') {
        numberLeaves(tree, n->leftc);
    }
    else {
        numberLeaves(tree, n->rightc);
        numberLeaves(tree, n->leftc);
    }
}

// Function to assign nullable
void assignNullable(Tree *tree, Node *n) {
    if(n == NULL)
        return;
    if(n->value == '|') {
        assignNullable(tree, n->leftc);
        assignNullable(tree, n->rightc);
        n->nullable = n->leftc->nullable || n->rightc->nullable;
    }
    else if(n->value == '.') {
        assignNullable(tree, n->leftc);
        assignNullable(tree, n->rightc);
        n->nullable = n->leftc->nullable && n->rightc->nullable;
    }
    else if(n->value == '*') {
        assignNullable(tree, n->leftc);
        n->nullable = true;
    }
    else {
        n->nullable = false;
    }
}

// Function to assign firstpos and lastpos
void assignFirstLastPos(Tree *tree, Node *n) {
    if(n == NULL)
        return;
    if(n->value == '|') {
        assignFirstLastPos(tree, n->leftc);
        assignFirstLastPos(tree, n->rightc);
        for(int i =0; i < n->leftc->firstpos.size; i++)
            addToIntSet(&(n->firstpos), n->leftc->firstpos.elements[i]);
        for(int i =0; i < n->rightc->firstpos.size; i++)
            addToIntSet(&(n->firstpos), n->rightc->firstpos.elements[i]);
        for(int i =0; i < n->leftc->lastpos.size; i++)
            addToIntSet(&(n->lastpos), n->leftc->lastpos.elements[i]);
        for(int i =0; i < n->rightc->lastpos.size; i++)
            addToIntSet(&(n->lastpos), n->rightc->lastpos.elements[i]);
    }
    else if(n->value == '.') {
        assignFirstLastPos(tree, n->leftc);
        assignFirstLastPos(tree, n->rightc);
        if(n->leftc->nullable) {
            for(int i =0; i < n->leftc->firstpos.size; i++)
                addToIntSet(&(n->firstpos), n->leftc->firstpos.elements[i]);
            for(int i =0; i < n->rightc->firstpos.size; i++)
                addToIntSet(&(n->firstpos), n->rightc->firstpos.elements[i]);
        }
        else {
            for(int i =0; i < n->leftc->firstpos.size; i++)
                addToIntSet(&(n->firstpos), n->leftc->firstpos.elements[i]);
        }
        if(n->rightc->nullable) {
            for(int i =0; i < n->leftc->lastpos.size; i++)
                addToIntSet(&(n->lastpos), n->leftc->lastpos.elements[i]);
            for(int i =0; i < n->rightc->lastpos.size; i++)
                addToIntSet(&(n->lastpos), n->rightc->lastpos.elements[i]);
        }
        else {
            for(int i =0; i < n->rightc->lastpos.size; i++)
                addToIntSet(&(n->lastpos), n->rightc->lastpos.elements[i]);
        }
    }
    else if(n->value == '*') {
        assignFirstLastPos(tree, n->leftc);
        for(int i =0; i < n->leftc->firstpos.size; i++)
            addToIntSet(&(n->firstpos), n->leftc->firstpos.elements[i]);
        for(int i =0; i < n->leftc->lastpos.size; i++)
            addToIntSet(&(n->lastpos), n->leftc->lastpos.elements[i]);
    }
    else {
        return;
    }
}

// Function to calculate followpos
void calculateFollowPos(Tree *tree, Node *n) {
    if (n == NULL)
        return;

    if (n->value == '.') {
        // For each position i in lastpos(c1), all positions in firstpos(c2) are in followpos(i)
        for (int i = 0; i < n->leftc->lastpos.size; i++) {
            int pos = n->leftc->lastpos.elements[i];
            for (int j = 0; j < n->rightc->firstpos.size; j++) {
                addToIntSet(&(tree->leaves.items[pos-1]->followpos), n->rightc->firstpos.elements[j]);
            }
        }
    }
    else if (n->value == '*') {
        // For each position i in lastpos(n), all positions in firstpos(n) are in followpos(i)
        for (int i = 0; i < n->lastpos.size; i++) {
            int pos = n->lastpos.elements[i];
            for (int j = 0; j < n->firstpos.size; j++) {
                addToIntSet(&(tree->leaves.items[pos-1]->followpos), n->firstpos.elements[j]);
            }
        }
    }

    // Recursively process left and right children
    calculateFollowPos(tree, n->leftc);
    calculateFollowPos(tree, n->rightc);
}

// Function to assign followpos
void assignFollowPos(Tree *tree, Node *n) {
    calculateFollowPos(tree, n);
}

// Function to check if two IntSets are equal
bool areIntSetsEqual(IntSet *a, IntSet *b) {
    if(a->size != b->size)
        return false;
    for(int i =0; i < a->size; i++) {
        bool found = false;
        for(int j =0; j < b->size; j++) {
            if(a->elements[i] == b->elements[j]) {
                found = true;
                break;
            }
        }
        if(!found)
            return false;
    }
    return true;
}

// Function to get State by value
State* getStateByValue(StateList *states, IntSet *value) {
    for(int i =0; i < states->size; i++) {
        if(areIntSetsEqual(&(states->items[i]->value), value))
            return states->items[i];
    }
    return NULL;
}

// Function to construct Dstates
void constructDstates(Tree *tree) {
    State *s0 = createState();
    for(int i =0; i < tree->root->firstpos.size; i++)
        addToIntList(&(s0->value), tree->root->firstpos.elements[i]);
    addToStateList(&(tree->Dstates), s0);
    Queue queue;
    initQueue(&queue);
    enqueue(&queue, s0);
    // Implement a simple processedStates as list of IntSets
    int processedCapacity = INITIAL_CAPACITY;
    int processedSize =0;
    IntSet *processedStates = (IntSet *)malloc(processedCapacity * sizeof(IntSet));
    initIntSet(&processedStates[processedSize]);
    for(int i =0; i < s0->value.size; i++)
        addToIntSet(&processedStates[processedSize], s0->value.items[i]);
    processedSize++;

    while(!isQueueEmpty(&queue)) {
        State *currentState = dequeue(&queue);
        // Iterate over alphabet
        for(int a =0; a < MAX_ALPHABET_SIZE; a++) {
```

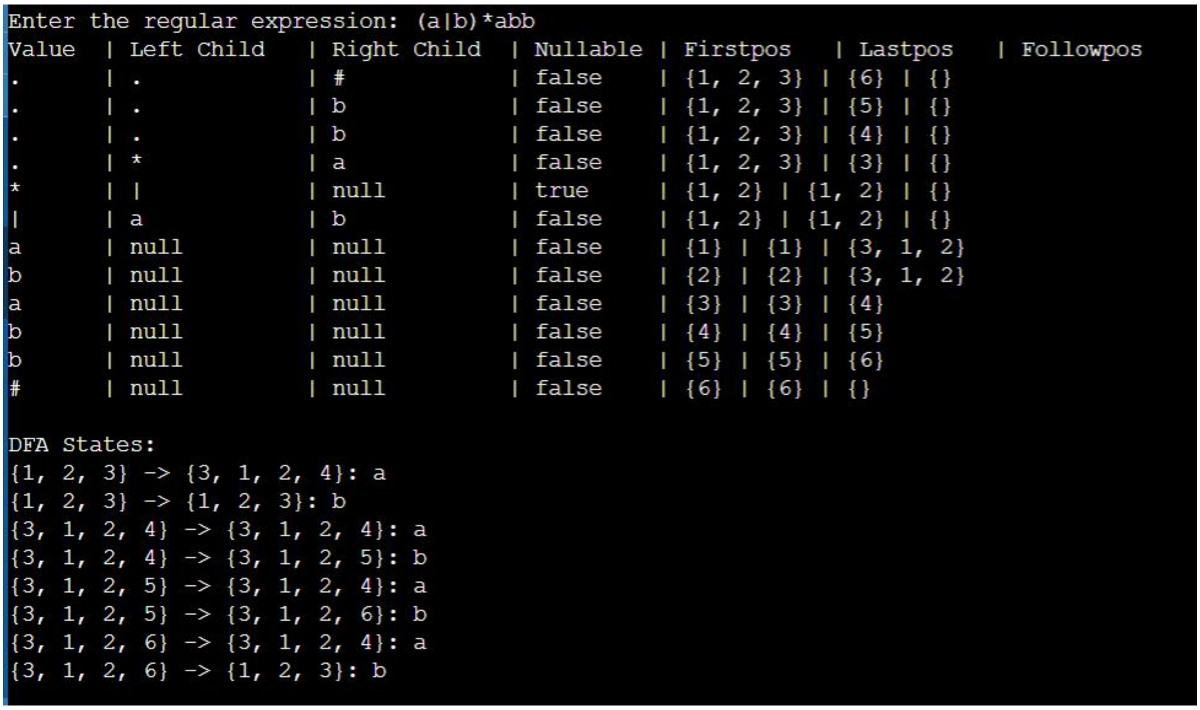
```
if(!tree->alphabet[a])
    continue;
IntSet U;
initIntSet(&U);
for(int p =0; p < currentState->value.size; p++) {
    int pos = currentState->value.items[p];
    Node *node = tree->leaves.items[pos-1];
    if(node->value == (char)a) {
        for(int f =0; f < node->followpos.size; f++)
            addToIntSet(&U, node->followpos.elements[f]);
    }
}
if(U.size ==0)
    continue;
// Check if U is already processed
bool found = false;
State *existingState = NULL;
for(int s =0; s < tree->Dstates.size; s++) {
    if(areIntSetsEqual(&U, &(tree->Dstates.items[s]->value))) {
        found = true;
        existingState = tree->Dstates.items[s];
        break;
    }
}
if(!found) {
    State *newState = createState();
    for(int u =0; u < U.size; u++)
        addToIntList(&(newState->value), U.elements[u]);
    addToStateList(&(tree->Dstates), newState);
    enqueue(&queue, newState);
    existingState = newState;
}
// Create Transition
Transition *trans = (Transition *)malloc(sizeof(Transition));
trans->from = currentState;
trans->to = existingState;
trans->value = (char)a;
```

```
            addToTransitionList(&(tree->Dtrans), trans);
        }
    }
    free(processedStates);
}

// Function to print DFA
void printDFA(Tree *tree) {
    printf("\nDFA States:\n");
    for(int i =0; i < tree->Dtrans.size; i++) {
        Transition *t = tree->Dtrans.items[i];
        printf("{");
        for(int j =0; j < t->from->value.size; j++) {
            printf("%d", t->from->value.items[j]);
            if(j < t->from->value.size -1) printf(", ");
        }
        printf("} -> {");
        for(int j =0; j < t->to->value.size; j++) {
            printf("%d", t->to->value.items[j]);
            if(j < t->to->value.size -1) printf(", ");
        }
        printf("}: %c\n", t->value);
    }
}

// Main function
int main() {
    Tree t;
    initTree(&t);
    char regex[100];
    printf("Enter the regular expression: ");
    fgets(regex, sizeof(regex), stdin);
    // Remove newline character
    regex[strcspn(regex, "\n")] = 0;
    parseRegex(&t, regex);
    numberLeaves(&t, t.root);
    assignNullable(&t, t.root);
    assignFirstLastPos(&t, t.root);
    assignFollowPos(&t, t.root);
    constructDstates(&t);
    printTree(&t);
    printDFA(&t);
    // Free allocated memory (not implemented for brevity)
    return 0;
}
```

Output:



```
Enter the regular expression: (a|b)*abb
Value   | Left Child    | Right Child   | Nullable | Firstpos    | Lastpos    | Followpos
.       | .             | #             | false    | {1, 2, 3} | {6} | {}
.       | .             | b             | false    | {1, 2, 3} | {5} | {}
.       | .             | b             | false    | {1, 2, 3} | {4} | {}
.       | *             | a             | false    | {1, 2, 3} | {3} | {}
*       | |             | null          | true     | {1, 2} | {1, 2} | {}
|       | a             | b             | false    | {1, 2} | {1, 2} | {}
a       | null          | null          | false    | {1} | {1} | {3, 1, 2}
b       | null          | null          | false    | {2} | {2} | {3, 1, 2}
a       | null          | null          | false    | {3} | {3} | {4}
b       | null          | null          | false    | {4} | {4} | {5}
b       | null          | null          | false    | {5} | {5} | {6}
#       | null          | null          | false    | {6} | {6} | {}

DFA States:
{1, 2, 3} -> {3, 1, 2, 4}: a
{1, 2, 3} -> {1, 2, 3}: b
{3, 1, 2, 4} -> {3, 1, 2, 4}: a
{3, 1, 2, 4} -> {3, 1, 2, 5}: b
{3, 1, 2, 5} -> {3, 1, 2, 4}: a
{3, 1, 2, 5} -> {3, 1, 2, 6}: b
{3, 1, 2, 6} -> {3, 1, 2, 4}: a
{3, 1, 2, 6} -> {1, 2, 3}: b
```

Conclusion

Hence by completing this experiment we came to know how to optimize DFA from RE.