

UNIT-II

Regular Expressions:

- * Introduction
- * Examples
- * Components
- * Operations.

Introduction: Regular Expressions are mathematical expressions describing a language which is accepted by FA.

* R.E describing a language called Regular language.

Definition:-

Let Σ be an alphabet then R.E over Σ is defined as follows.

- * \emptyset is a R.E then that describes an empty set. R.E = \emptyset .
- * ϵ is a R.E then that describes "NULL" string set. R.E = ϵ , R.E = { ϵ }
- * a is a R.E over Σ then that describes the set with a. R.E = { a }
- * Let r and s are two R.E and L_1 and L_2 are two languages which are described by r and s . then,
 - i) $r+s$ is equivalent to $L_1 \cup L_2$
 - ii) rs is equivalent to $L_1 L_2$ (or) $L_1 \cup L_2$
 - iii) r^* is equivalent to L^*

Components:-

union, concatenation, Kleene closure.

Example:-

- 1) Write the R.E for the language accepting all combinations of a's over $\Sigma = \{a\}$

Sol:- $\Sigma = \{a\}$

$$L = \{ \epsilon, a, aa, aaa, aaaa, \dots \}$$

$= a^*$

$\therefore R.E = a^*$

- 2) Write a R.E for the language accepting all combinations of a's except empty string over $\Sigma = \{a\}$

Sol:- $\Sigma = \{a\} \{aa, aaa, aaaa, \dots\}$

$$= a^*$$

$$\therefore R.E = a^*$$

- 3) Write a R.E for the language accepting any no. of a's and b's over $\Sigma = \{a, b\}$

Sol:-

$$\Sigma = \{a, b\}$$

$$\begin{aligned} L &= \{\epsilon, a'b', a^2, ab, ba, b^2, \dots\} \\ &= \{\epsilon, a, b, aa, ab, ba, bb, \dots\} \\ &= (a+b)^* \end{aligned}$$

$$\therefore R.E = (a+b)^*$$

- 4) Write a R.E for the language containing all strings which are ending with 00 over $\Sigma = \{0, 1\}$

Sol:-

$$\Sigma = \{0, 1\}$$

$$L = \{ \underbrace{(0+1)^*}_{+} 00 \}$$

$$\therefore R.E = (0+1)^* 00$$

- 5) Write a R.E for the language Accepting set of all string which are starting with '1' and ending with '0' over $\Sigma = \{0, 1\}$

Sol:-

$$\Sigma = \{0, 1\}$$

$$1 \underbrace{(0+1)^*}_{+} 0$$

$$\therefore R.E = 1 \underbrace{(0+1)^*}_{+} 0$$

- 6) Write a R.E for the language accepting any no. of a's followed by any no. of b's, followed by any no. of c's over $\Sigma = \{a, b, c\}$

Sol:-

$$\Sigma = \{a, b, c\}$$

$$\therefore R.E = a^* b^* c^*$$

- 7) Write a R.E for the language accepting set of all strings which contains the third character from the right end of the string is always 'a' over $\Sigma = \{a, b\}$.

$$\therefore R.E = (a+b)^* a \underbrace{(a+b)}_{+} (a+b)$$

Sol:-

$$\Sigma = \{a, b\}$$

$$(a+b)^* \underbrace{a}_{+} \underbrace{(a+b)}_{+} (a+b)$$

language Associated with RE:-

- * A language which is described by RE is called Regular language.
- * Let R be a RE then the language accepted by R is denoted by $L(R)$.

Ex:- If the RE $R = (ba)^*$ then $L(R) = ?$

$$\text{Sol:- } R = (ba)^*$$

$$L(R) = \{(ba)^0, (ba)^1, (ba)^2, (ba)^3, \dots\}$$

$$= \{\epsilon, ba, baba, bababa, \dots\}$$

Properties of RE (Identity rules):

Let R, S be RE then the following properties are two

$$1) (R+S)+T = R+(S+T) \quad 11) R^* R^* = R^* = (R^*)^*$$

$$2) R+R = R.$$

$$12) RR^* = R^* R = R^*$$

$$3) R^*\emptyset = \emptyset + R = R$$

$$13) (R+S)^* = (R^* S^*)^* = (R^* + S^*)^*$$

$$4) R\emptyset = \emptyset R = \emptyset$$

$$14) (R.S)^* = (R^* S^*)^* = (R^* S^*)^*$$

$$5) R+S = S+R$$

$$6) RE = \epsilon R = R$$

$$7) R(ST) = (RS)T$$

$$8) R(S+T) = RS+RT$$

$$9) (S+T)R = SR+TR$$

$$10) \emptyset^* = \epsilon^* = \epsilon$$

Manipulation of RE (Basic operations)

- i) Union
- ii) concatenation
- iii) Kleene closure.

UNION:-

Let R, S be two RE then union of R, S is defined as

$$RUS = \{x \mid x \in R \text{ or } x \in S\}$$

Ex:- If $R = \{ab, c\}$ and $S = \{d, ef\}$ then $RUS = ?$

$$RUS = \{ab, c, def\}$$

concatenation:-

Let R, S be two RE then concatenation of R, S is

$$\text{defined as } RS = \{xy \mid x \in R \text{ and } y \in S\}$$

Ex :- If $R = \{ab, c\}$ and $S = \{d, ef\}$ then $RS = ?$

Sol :- $RS = \{ab, c\} \{d, ef\}$
 $= \{abd, abef, cd, cef\}$

Kleene closure :-

Let ' R ' be a R.E then the Kleene closure of R is denoted as R^* which contains set of all strings including null string.

Ex :- If $R = \{ab\}$ then $R^* = ?$

Sol :- $R^* = \{(ab)^0, (ab)^1, (ab)^2, (ab)^3, \dots\}$
 $= \{\epsilon, ab, abab, ababab, \dots\}$

examples :-

construct a string set for the R.E given below.

i) ab^*a

Sol :- $\{ab^0a, ab^1a, ab^2a, \dots\}$
 $\{\epsilon, aba, abaa, \dots\}$

ii) 1^*0

$$\begin{aligned} & \{1^0, 1^1, 1^2, 1^3, 1^4, \dots\}0 \\ &= \{\epsilon, 1, 11, 111, 1111, \dots\}0 \\ &= \{0, 10, 110, 1110, 11110, \dots\} \end{aligned}$$

iii) 00^*

$$\begin{aligned} &= \{00^0, 00^1, 00^2, 00^3, 00^4, \dots\} \\ &= \{0, 00, 000, 0000, 00000, \dots\} \end{aligned}$$

$= 0^+$

iv) $(100^+)^*$

$$= (10\{0^0, 0^1, 0^2, 0^3, \dots\})^*$$

$$= (100, 1000, 10000, \dots)^*$$

$$= ((100)^*, (1000)^*, (10000)^*)$$

$$= (\{\epsilon, 100, 100100, 100100100, \dots\}, \{\epsilon, 1000, 10001000, 100010001000, \dots\}, \{\epsilon, 10000, 1000010000, \dots\})$$

$$\therefore \{\epsilon, 100, 100100, 10001000, 1000010000, \dots\}$$

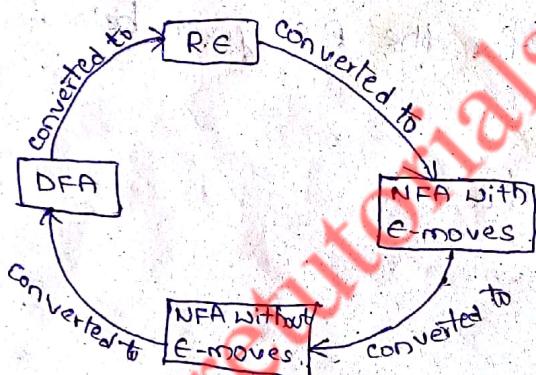
$$v) (0+1)^* = 0^* + 1^* \\ = \{ \epsilon, 0, 00, 000, \dots \} \cup \{ \epsilon, 1, 11, 111, 1111, \dots \} \\ = \{ \epsilon, 0, 00, 000, \dots, 1, 11, 111, 1111, \dots \}$$

$$vi) (0+1)^* 011 \\ = (0^* + 1^*) 011 \\ = ((\{ \epsilon, 0, 00, 000, \dots \} \cup \{ \epsilon, 1, 11, 111, \dots \}) 011) \\ = (\{ \epsilon, 0, 00, 000, \dots, 1, 11, 111, \dots \}) 011 \\ = \{ 011, 0011, 00011, 000011, \dots, 1011, 11011, 111011, \dots \}$$

Equivalence of R.E and FA:

1. Conversion of R.E to FA
2. Conversion of FA to R.E

Relationship b/w R.E and FA:



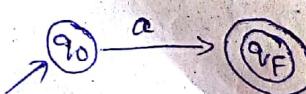
1. Conversion of R.E to FA:

Basic notations used.

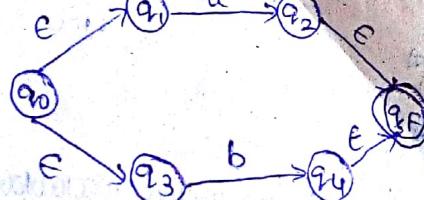
1. If the R.E is like $\sigma = \epsilon$ then FA is



2. If the R.E is like $\sigma = a$ then FA is



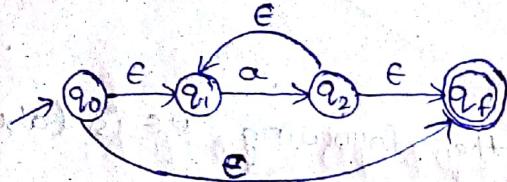
3. If the R.E is like $\tau = a+b$ then FA is



4. If the RE is like $\eta = ab$ then FA is



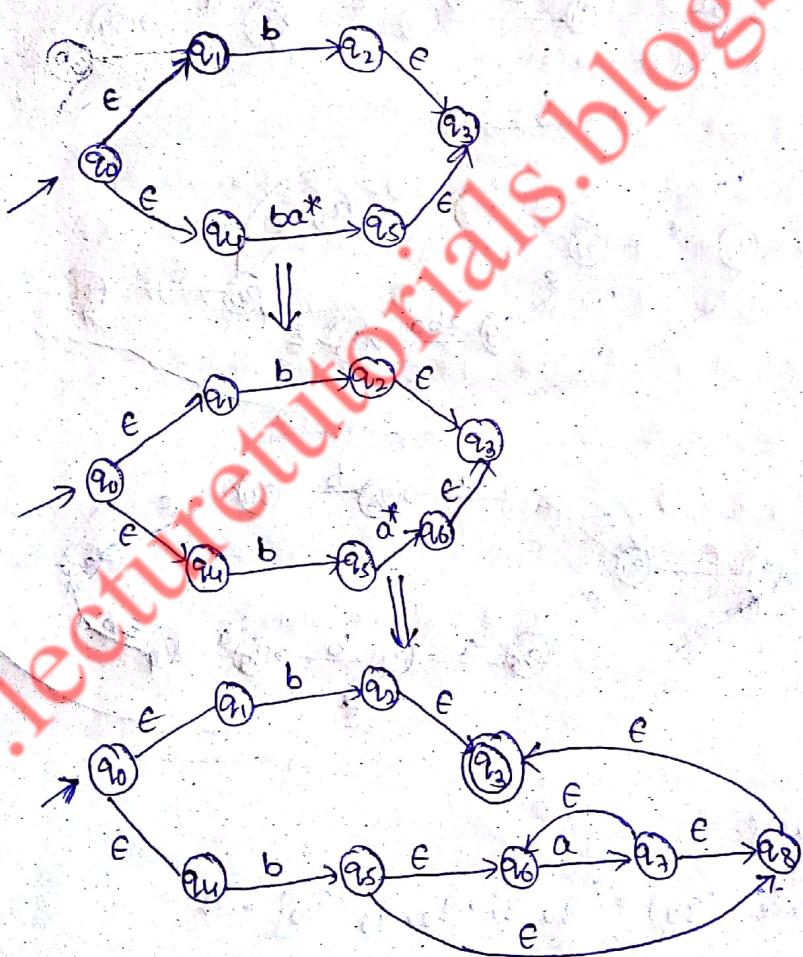
5. If the RE is like $\eta = a^*$ then FA is



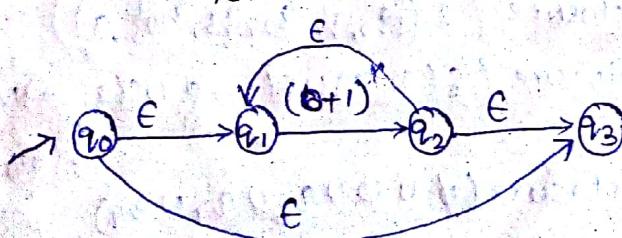
Examples:

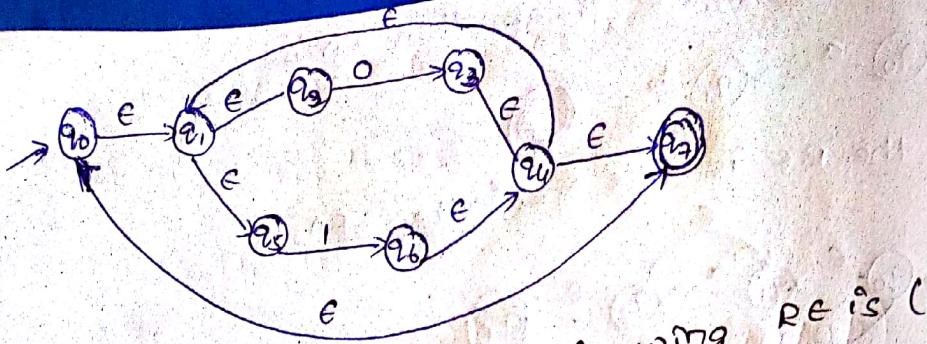
1) Construct an NFA with ϵ -moves for the RE $b + ba^*$

Sol: The given RE $\eta = b + ba^*$



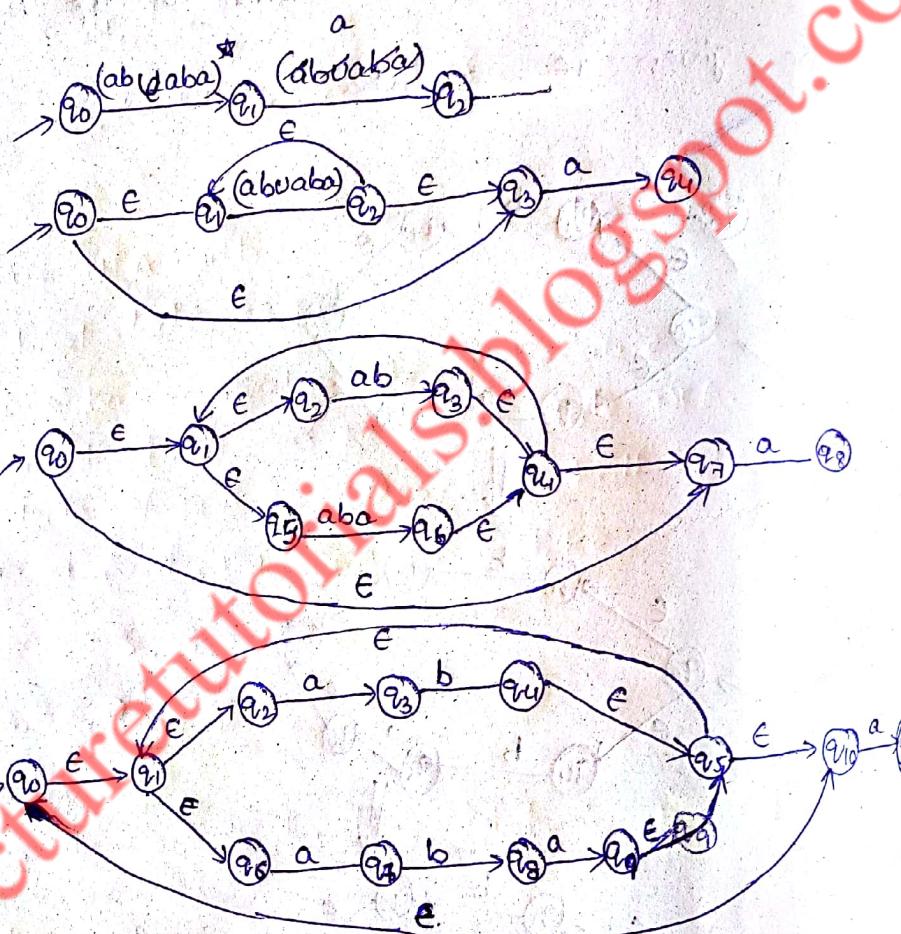
2) construct an NFA with ϵ -moves for the RE is $(\eta + 1)^*$





3) Construct a DFA for the following.
The given RE is $(abuaba)^*$

RE is $(abuaba)^*$



$$\Sigma = \{a, b\}$$

$$\epsilon\text{-closure}(q_0) = \{q_0, q_1, q_2, q_6, q_{10}\} = A$$

$$\begin{aligned}
 g^*(A, a) &= \epsilon\text{-closure}(g(A, a)) \\
 &= \epsilon\text{-closure}(g(\{q_0, q_1, q_2, q_6, q_{10}\}, a)) \\
 &= \epsilon\text{-closure}(g(q_0, a) \cup g(q_1, a) \cup g(q_2, a) \cup g(q_6, a) \cup g(q_{10}, a)) \\
 &= \epsilon\text{-closure}(\emptyset \cup \{q_3\} \cup \{q_7\} \cup \{q_{11}\}) \\
 &= \epsilon\text{-closure}(q_3) \cup \epsilon\text{-closure}(q_7) \cup \epsilon\text{-closure}(q_{11})
 \end{aligned}$$

$$= \{q_3\} \cup \{q_7\} \cup \{q_{11}\}$$

$$= \{q_3, q_7, q_{11}\} = B$$

$$s^1 f(A, b) = \text{e-closure}(s, (A, b))$$

$$= \text{e-closure}(s(\{q_0, q_1, q_2, q_6, q_{10}\}), b)$$

$$= \text{e-closure}(\emptyset \cup \emptyset \cup \emptyset \cup \emptyset)$$

$$= \emptyset$$

$$s^1 (B, a) = \text{e-closure}(s, (B, a))$$

$$= \text{e-closure}(s(\{q_3, q_7, q_{11}\}, a))$$

$$= \text{e-closure}(\emptyset \cup \emptyset \cup \emptyset)$$

$$= \emptyset$$

$$s^1 (B, b) = \text{e-closure}(s(B, b))$$

$$= \text{e-closure}(s(\{q_3, q_7, q_{11}\}, b))$$

$$= \text{e-closure}(q_4 \cup q_8 \cup \emptyset)$$

$$= \text{e-closure}(q_4) \cup \text{e-closure}(q_8)$$

$$= \text{e-closure}(q_4, q_5, q_{10}, q_6, q_2, q_8) \cup \{q_8\}$$

$$= \{q_1, q_2, q_4, q_5, q_6, q_8, q_{10}\}$$

$$= C.$$

$$s^1 (C, a) = \text{e-closure}(s(C, a))$$

$$= \text{e-closure}(s(\{q_1, q_2, q_4, q_5, q_6, q_8, q_{10}\}, a))$$

$$= \text{e-closure}(\emptyset \cup q_3 \cup \emptyset \cup \emptyset \cup q_7 \cup q_9 \cup q_{11})$$

$$= \text{e-closure}(q_3) \cup \text{e-closure}(q_7) \cup \text{e-closure}(q_9) \cup \text{e-closure}(q_{11})$$

$$= \{q_3\} \cup \{q_7\} \cup \{q_9, q_5, q_{10}, q_1, q_2, q_6\} \cup \{q_{11}\}$$

$$= \{q_1, q_2, q_3, q_5, q_6, q_7, q_9, q_{10}, q_{11}\}$$

$$= D$$

$$s^1 (C, b) = \text{e-closure}(s(C, b))$$

$$= \text{e-closure}(s(\{q_1, q_2, q_4, q_5, q_6, q_8, q_{10}\}, b))$$

$$= \text{e-closure}(\emptyset \cup \emptyset \cup \emptyset \cup \emptyset \cup \emptyset \cup \emptyset \cup \emptyset)$$

$$= \emptyset$$

$$s^1 (D, a) = \text{e-closure}(s(D, a))$$

$$= \text{e-closure}(\emptyset \cup q_3 \cup \emptyset \cup q_7 \cup \emptyset \cup q_1 \cup \emptyset)$$

$$\begin{aligned}
 &= \epsilon\text{-closure}\{q_3\} \cup \epsilon\text{-closure}\{q_7\} \cup \epsilon\text{-closure}\{q_{11}\} \\
 &= \{q_3\} \cup \{q_7\} \cup \{q_{11}\} \\
 &= B.
 \end{aligned}$$

$$\begin{aligned}
 s'(D, b) &= \epsilon\text{-closure}(s(D, b)) \\
 &= \epsilon\text{-closure}(\phi \cup \phi \cup q_4 \cup \phi \cup \phi \cup q_8 \cup \phi \cup \phi \cup \phi) \\
 &= \epsilon\text{-closure}(q_4) \cup \epsilon\text{-closure}(q_8) \\
 &= \{q_4, q_5, q_1, q_{10}, q_2, q_6\} \cup \{q_8\} \\
 &= \{q_1, q_2, q_4, q_5, q_6, q_8, q_{10}\} \\
 &= C.
 \end{aligned}$$

The previous NFA with ϵ -moves has the initial state as q_0 and final state as q_{11} .

Now the DFA has initial state A because it contains q_0 as an element which can be initial state NFA.

The final state of DFA is B, D because both states contain q_{11} as an element. The DFA 'M' is like,

$$M = \{Q, \Sigma, S, S_0, F\} \text{ where}$$

$$Q = \{A, B, C, D\}$$

$$\Sigma = \{a, b\}$$

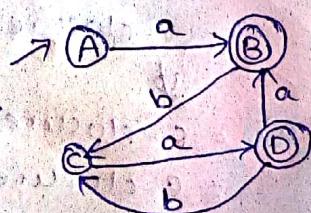
S : is a transition function which is defined as.

$s:$	a	b
A	B	ϕ
B	ϕ	C
C	D	ϕ
D	B	C

$$q_0 = a$$

$$f = \{b, d\}$$

\therefore transition diagram for DFA is.



2nd method:

conversion of FA to R.E.

ARDEN'S Theorem:-

Let P and Q be two R.E. over the input alphabet Σ .

The R.E 'R' is given as $R = Q + RP$ which has a unique solution. $R = QP^*$

conversion algorithm:

* Let q_1 be a initial state.

* There are $q_2, q_3, q_4, \dots, q_n$ are no. of states. The final state may be some q_j where $j \leq n$.

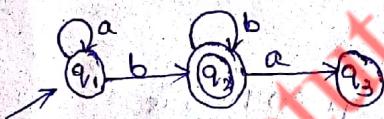
* Let α_{ij} be a transition from q_i to q_j state.

* calculate $q_j = \alpha_{ij} q_i + \epsilon$. If q_j is an initial state then

$$q_j = \alpha_{ij} q_i + \epsilon$$

* Similarly compute the final state equation which gives the R.E.

Ex:- Construct R.E. from given DFA.



Sol: $q_1 = aq_1 + \epsilon \rightarrow ①$

$$q_2 = bq_1 + bq_2 \rightarrow ②$$

$$q_3 = aq_2 \rightarrow ③$$

$$q_1 = aq_1 + \epsilon \quad \left(\begin{array}{l} R = Q + RP \\ R = QP^* \end{array} \right)$$

where

$$R = q_1$$

$$Q = \epsilon$$

$$P = \alpha$$

solution for above equ. is.

$$R = QP^*$$

$$q_1 = \epsilon a^*$$

$$q_1 = a^* \rightarrow ④$$

Substitute equ ④ in equ ②

$$q_2 = bq_1 + bq_2$$

$$q_2 = ba^* + bq_2$$

$$q_2 = ba^* b^*$$

$$= a^* bb^*$$

$$= a^* b^*$$

The R.E is $a^* b^*$

Construct R.E from given DFA



$$\text{Sd: } q_1 = 0q_1 + \epsilon \rightarrow ①$$

$$q_2 = 1q_1 + 1q_2 \rightarrow ②$$

$$q_3 = 0q_2 + 0q_3 + 1q_3 \rightarrow ③$$

$$q_1 = 0q_1 + \epsilon$$

$$q_1 = \epsilon + 0q_1 \quad (\therefore R = Q + RP \Rightarrow R = QP^*)$$

$$q_1 = \epsilon 0^*$$

$$q_1 = 0^* \rightarrow ④$$

check equ ④ & equ ②

$$q_2 = 1q_1 + 1q_2$$

$$q_2 = 10^* + 1q_2$$

$$q_2 = 10^* 1^*$$

$$= 0^* 11^*$$

$$= 0^* 1^*$$

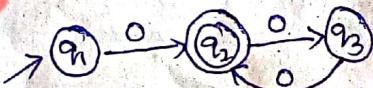
∴ The regular expression for given DFA is

$$q_1 + q_2 = 0^* + 0^* 1^*$$

$$= 0^* (\epsilon + 1)$$

$$= 0^* 1^*$$

Construct R.E from given DFA.



$$\text{Sd: } q_1 = \epsilon \rightarrow ①$$

$$q_2 = 0q_1 + 0q_3 \rightarrow ②$$

$$q_3 = 0q_2 \rightarrow ③$$

check equ ① & equ ②

$$q_2 = 0q_1 + 0q_3$$

$$= 0 \cdot \epsilon + 0 \cdot q_3$$

$$q_2 = 0 + 0q_3 \rightarrow ④$$

sub E_{que}(3) in E_{que}(4)

$$q_2 = 0 + 0 \cdot q_3$$

$$q_2 = 0 + 0 \cdot q_2$$

$$q_2 = 0(00)^*$$

The R.E for given DFA is

$$0(00)^*$$

//

Applications of R.E:-

* R.E are used for describing a language called Regular language.

* R.E are used to implement lexical analysis in Compiler design.

* R.E are used to represent a set of strings in UNIX programming.

Closure properties of Regular languages:-

* Regular languages are closed under Union.

* " " " " " Intersection

* " " " " " concatenation

* " " " " " Kleene closure

* " " " " " Difference

* " " " " " Complement

* " " " " " Reverse

* " " " " " Symmetric difference

* " " " " " Homomorphism

* " " " " " Inverse homomorphism

Regular Grammar and FA:-

* Grammar

* Regular Grammar

1. left linear Grammar

2. Right linear Grammar

* FA from Regular Grammar

* RG from FA

* RE from RG.

Grammar:-

Grammar is a set that contains four types like.

$$G = (V, T, P, S)$$

Regular grammar from FA :-

Let $M = (\mathcal{Q}, \Sigma, \delta, q_0, F)$ be a FA. It contains some'n' no. of states like $\mathcal{Q} = \{q_1, q_2, \dots, q_n\}$ and $\Sigma = \{a_1, a_2, a_3, \dots, a_n\}$. Therefore the Regular grammar $G = (V, T, P, S)$ is defined as

$$V = \{q_1, q_2, \dots, q_n\}$$

$$T = \Sigma = \{a_1, a_2, \dots, a_n\}$$

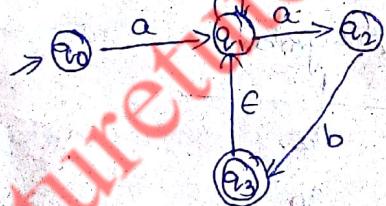
$$S = \mathcal{E} = q_0$$

$P = \text{Transitions of FA}$.

Rules :-

- * If the transition of FA is like $q_i \xrightarrow{a} q_j$ then the production rule is $q_i \rightarrow a q_j$.
- * If there is a final state in FA is like q_i then the production rule is $q_i \rightarrow \epsilon$.
- * If the transition of FA is like $q_i \xrightarrow{a} q_j$ then the production rules are $q_i \rightarrow a q_j$, $q_i \rightarrow a$.

To :- construct RG from the given FA.



Sol :- The given FA is like $M = (\mathcal{Q}, \Sigma, \delta, q_0, F)$

$$\text{where } \mathcal{Q} = \{q_0, q_1, q_2, q_3\}$$

$$\Sigma = \{a, b, \epsilon\}$$

δ is a transition function is defined as.

δ : states	input symbols		
	a	b	ϵ
q_0	q_1	\emptyset	\emptyset
q_1	q_2	q_1	\emptyset
q_2	\emptyset	q_3	\emptyset
q_3	\emptyset	\emptyset	q_1

$$q_0 = q_0$$

$$F = \{q_3\}$$

Now, therefore the equivalent regular grammar of M is defined as $G = (V, T, P, S)$ where.

$$V = \{q_0, q_1, q_2, q_3\}$$

$$T = \{a, b, \epsilon\}$$

P is a set of production rules defined from transitions of M is like.

$P:$

$$\{q_0 \rightarrow aq_1\}$$

$$q_1 \rightarrow aq_2$$

$$q_1 \rightarrow bq_1$$

$$q_2 \rightarrow bq_3$$

$$q_2 \rightarrow b\epsilon$$

$$S = \{q_0\} \quad q_3 \rightarrow \epsilon q_1\}$$

2) Construct R.G from the given FA.

Sol: The given FA is like.

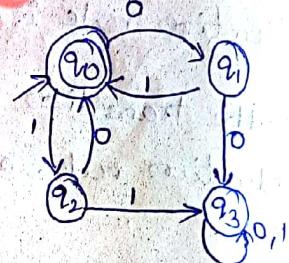
$$M = (Q, \Sigma, S, q_0, F)$$

$$Q = \{q_0, q_1, q_2, q_3\}$$

$$\Sigma = \{0, 1\}$$

S:

states	input symbols	
	0	1
$\rightarrow q_0$	q_1 q_2	
q_1	q_3 q_0	
q_2	q_0 q_3	
q_3	q_3 q_3	



now, therefore the equivalent RG of M is defined as $G = (V, T, P, S)$ where.

$$V = \{q_0, q_1, q_2, q_3\}$$

$$T = \{0, 1\}$$

P is a set of production rules defined from transitions of M is like

$$P: \{q_0 \rightarrow 0q_1, q_1 \rightarrow 1, q_3 \rightarrow 1q_3, q_0 \rightarrow 1q_2, q_2 \rightarrow 0q_2, q_2 \rightarrow 0, q_1 \rightarrow 0q_3, q_2 \rightarrow 1q_3, q_1 \rightarrow 0q_0, q_3 \rightarrow 0q_3\}$$

Finite automata from RG:-

Let $G = (V, T, P, S)$ be a RG. We can construct DFA 'M' whose

1. states corresponds to variables 'V'

2. starting state corresponds to start symbol's.

3. Transitions in 'M' corresponding to production Rules in 'P'.

4. Input symbols corresponding to terminals in 'T'.

5. If there is a production is of the form $q_i \rightarrow a$ then
the transition is terminate at a new state called
final state

Rules:-

* If the production rule is of the form $A \rightarrow E$ then 'A' is
the final state (A_f) .

* A production rule is of the form $A_i \rightarrow a$ then there is
a transition from A_i to final state labelled with 'a'.

$$A_i \rightarrow a = (A_i) \xrightarrow{a} (A_f)$$

* A production rule is of the form $A_i \rightarrow aA_j$; then there
is a transition from A_i to A_j labelled with 'a'.

$$(A_i) \xrightarrow{a} (A_j)$$

* If a production rule is of the form $A_i \rightarrow a_1 a_2 a_3 \dots a_m$
 A_j then there is a transition from A_i to A_j and add
intermediate states labelled by $a_1, a_2, a_3, \dots, a_m$.

$$A_i \xrightarrow{a_1} (x_1) \xrightarrow{a_2} (x_2) \xrightarrow{a_3} (x_3) \dots \xrightarrow{a_m} (A_j)$$

Ex: Construct a FA from the RG.

$$S \rightarrow a A/B$$

$$A \rightarrow aAB$$

$$B \rightarrow bB/a$$

Sol: The Given $G = (V, T, P, S)$ where

$$V = \{S, A, B\}$$

$$T = \{a, b\}$$

$$P = \begin{cases} S \rightarrow aA & B \rightarrow a \\ S \rightarrow B & \end{cases}$$

$$A \rightarrow aAB$$

$$B \rightarrow bB$$

$$S = \{s\}$$

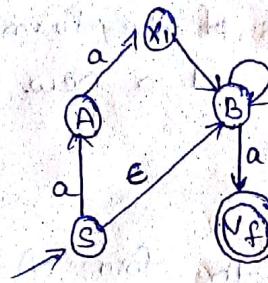
∴ The equivalent DFA M is

$$M = (Q, \Sigma, S, q_0, F) \text{ where}$$

$$Q = \{S, A, B, V_f\}$$

$$\Sigma = \{a, b\}$$

8:



$$Q = \{S, A, B, V_f, x_1\}$$

$$\Sigma = \{a, b, e\}$$

$$q_0 = \{S\}$$

$$F = \{V_f\}$$

2) Construct FA from the given RG.

$$S \rightarrow aA/e$$

$$A \rightarrow aA/bB/e$$

$$B \rightarrow bB/e$$

Sol:- The given $G = (V, T, P, S)$

$$V = \{S, A, B\}$$

$$T = \{a, b, e\}$$

$$P = \{S \rightarrow aA$$

$$S \rightarrow e$$

$$A \rightarrow aA$$

$$A \rightarrow bB$$

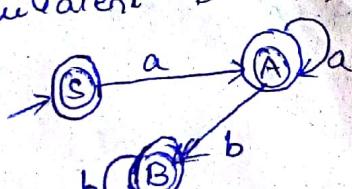
$$A \rightarrow e$$

$$B \rightarrow bB$$

$$B \rightarrow e\}$$

$$S = \{S\}$$

The equivalent DFA M is $M = (Q, \Sigma, S, q_0, F)$



$$Q = \{S, A, B\}$$

$$\Sigma = \{a, b, e\}$$

$$q_0 = \{S\}$$

Regular Expression from Regular grammar:

Let $G = (V, T, P, S)$ be a R.G. Now the R.E 'R' is defined from 'G' by using the following rules.

* Replace the ' \rightarrow ' in the grammar productions with equal symbol ($=$) to get the set of equations.

* convert the equation of the form $A \rightarrow aA/b$

$$A = a^*ab$$

* Repeat the step 2 until we get the R.E for the starting symbol. This gives the final R.E of given grammar 'G'.

To :- obtain the Regular Expression from the grammar given below.

$$S \rightarrow 0IB|0$$

$$B \rightarrow IB|I$$

Sol :- The given Regular Grammar $G = (V, T, P, S)$

where

$$V = \{S, B\}$$

$$T = \{0, 1\}$$

$$P = \{S \rightarrow 0IB$$

$$S \rightarrow 0$$

$$B \rightarrow IB$$

$$B \rightarrow I\}$$

$$S = \{S\}$$

Replace arrow from set of productions with equal ($=$)

$$S = 0IB|0$$

$$B = IB|I$$

\downarrow

$$B = I^*I$$

$$B = I^*$$

$$\text{sub } B = I^* \text{ in } S = 0IB|0$$

$$S = 0I^*|0$$

The Final RE is

$$S = 0I^* + 0$$

$$= 0(I^* + 0)$$

$$= 0I^*$$

2)

$$S \rightarrow bas/aA$$

$$A \rightarrow bba/bb$$

\therefore The given RG $G = (V, T, P, S)$

$$V = \{S, A\}$$

$$T = \{a, b\}$$

$$P = \{S \rightarrow bas$$

$$S \rightarrow aA$$

$$A \rightarrow bba$$

$$A \rightarrow bb\}$$

Replace arrow from set of productions with '='

$$S = bas/aA$$

$$A = bba/bb$$

$$S = bas/aA$$

$$A = bba/bb$$

$$A = bb^*bb$$

$$S = ba^*aA$$

$$\text{Sub } A = bb^*bb \text{ in } S = ba^*aA$$

$$S = ba^*abb^*bb$$

$$\boxed{\begin{aligned} R.E &= ba^*abb^*bb \\ &= ba^*b^*bb \end{aligned}}$$

Introduction :-

* Pumping Lemma is used for checking the given language Regular (or) not.

* Let $M = (Q, \Sigma, \delta, q_0, F)$ be a FA with 'm' states.

* Let 'L' be a Regular language accepted by 'M'

* Let 'w' belongs to L ($w \in L$) and there exists x, y, z such that $w = xyz$ and $xy^iz \in L$ for each $i \geq 0$.

Application:-

Step 1:- Assume 'L' be regular language and 'n' is the no. of states in the FA.

2:- choose the string 'w' such that $|w| \leq n$. use pump lemma to write $w = xyz$ with the conditions.

i) $|xy| < n$

ii) $|y| > 0$

3:- find a suitable integer 'i' such that $xy^i \notin L$. Hence, 'L' is not regular.

examples:-

1) S.T the set $L = \{0^{i^2} \mid i \geq 1\}$ is not regular.

Sol:- Given $L = \{0^{i^2} \mid i \geq 1\}$

$$L = \{0^1, 0^4, 0^9, 0^{16}, \dots\}$$

$$L = \{0^1, 0^4, 0^9, 0^{16}, \dots\}$$

Assume $w = 0^{i^2}$



for $i=2$

$$xy^2 = 0^{i^2-3} 0^2 0^2$$

$$= 0^{i^2+1}$$

$$= 0^5$$

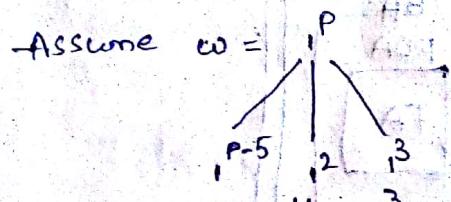
$$= 0^5 \notin L$$

The given set is not regular.

2) S.T the set $L = \{p^p \mid p \text{ is prime}\}$ is not regular.

Sol:- Given $L = \{p^p \mid p \text{ is prime}\}$

$$L = \{2^2, 3^3, 5^5, 7^7, 11^{11}, 13^{13}, \dots\}$$



for $i=2$

$$xy^2 = p-5 - (2)^2 (3)$$

$$= p-5$$

$$14$$

$$13$$

$$= p+2$$

$\therefore L$ is not regular.