UNIT-IV

Deterministic push down Automata

Left Recursion

it means on the left hand side we will have a variable

Ex:-

$A \rightarrow A\alpha$

$A \rightarrow A\alpha_1 / A\alpha_2 / A\alpha_3 / A\alpha_n /$
$\beta_1 / \beta_2 / \beta_3 / \dots / \beta_m$

then replace it with new variable A'

$A \rightarrow \beta_1 A' / \beta_2 A' / \beta_3 A' / \dots / \beta_m A'$
$A' \rightarrow \alpha_1 A' / \alpha_2 A' / \dots / \alpha_n A' / \varepsilon$

Q) Eliminate the left recursion from the following grammar

$E \rightarrow E + T / T$
$T \rightarrow T * F / F$
$F \rightarrow (E) / id$

→

Given	Substitution	without left recursion
$\underset{A}{E} \rightarrow \underset{A}{E} \underset{\alpha}{+T} / \underset{\beta_1}{T}$	$A = E$ $\beta_1 = T$ $\alpha_1 = +T$	$E \rightarrow TE'$ $A \rightarrow \beta_1 A'$ $\underset{A'}{E'} \rightarrow +TE'/\varepsilon$ $\alpha_1 A' / \varepsilon$
$T \rightarrow T * F / F$	$A = T$ $\beta_2 = F$ $\alpha_2 = *F$	$A \rightarrow \beta_2 A'$ $T \rightarrow FT'$ $A' \rightarrow \alpha_2 A' / \varepsilon$ $T' \rightarrow *FT'/\varepsilon$

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Third production is not in left recursion so we will write it as it is.

$F \rightarrow (E)/id$

∴ grammar $G = (V, T, P, S)$

$V = \{E, E', T, T', F\}$

$T \rightarrow \{+, *, id, (,)\}$

$P = \{ E \rightarrow TE'$
$E' \rightarrow +TE'/\epsilon$
$T \rightarrow FT'$
$T' \rightarrow *FT'/\epsilon$
$F \rightarrow (E)/id$
$\}$

here start symbol S is E

Q) $S \rightarrow Ab/a$
$A \rightarrow Ab/Sa$

→ $S \rightarrow Ab$
$S \rightarrow Sab$ so left recursion

$A \rightarrow Ab/Sa$
$S \rightarrow Ab$
$A \rightarrow Ab/(Ab/a)a$
$S \rightarrow Sab$
$A \rightarrow Ab/Aba/aa$.

The non terminal S even though there is no immediate left recursion since $S \rightarrow Ab$ so $S \rightarrow Sab$ when A is replaced by Sa ($\because A \rightarrow Sa$). So in

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order to eliminate the left recursion, substitute S in the A production can eliminate indirect left recursion.

The productions we get are
$S \rightarrow Sab$
$A \rightarrow Ab / Aba / aa$

Given	substitution	without left recursion
$A \rightarrow \underset{\alpha_1}{Ab} / \underset{\alpha_2}{Aba} / \underset{\beta_1}{aa}$	$A = A$	$\overset{A \rightarrow \beta\,A'}{A \rightarrow aaA'}$
	$\alpha_1 = b$	$A' \rightarrow bA' / baA' /$
	$\alpha_2 = ba$	ϵ
	$\beta_1 = aa$	$A' \rightarrow \alpha_1 A' / \alpha_2 A' / \epsilon$

Q) $A \rightarrow ABd / Aa / a$
$B \rightarrow Be / b$

$\Rightarrow$

Given	substitution	without left recursion
$A \rightarrow A\underset{\alpha_1}{Bd} / A\underset{\alpha_2}{a} / \underset{\beta}{a}$	$A \rightarrow A$	$\overset{A \rightarrow \beta A'}{A \longrightarrow aA'}$
	$\alpha_1 \rightarrow Bd$	$A' \rightarrow \alpha_1 A' / \alpha_2 A' / \epsilon$
	$\alpha_2 \rightarrow a$	$A' \rightarrow BdA' / aA' / \epsilon$
	$\beta_1 \rightarrow a$	
$B \rightarrow B\underset{\alpha_1}{e} / \underset{\beta_1}{b}$	$A = B$	$B \rightarrow bB'$
	$\alpha_1 = e$	$A \rightarrow \beta_1 A'$
	$\beta_1 = b$	$B' \rightarrow eB' / \epsilon$
		$A' \rightarrow \alpha_1 A' / \epsilon$

$\therefore$ grammar $G = (V, T, P, S)$
$V = \{A, A', B, B'\}$
$T = \{a, d, e, b\}$

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$P = \{ \; A \rightarrow aA'$

$A' \rightarrow BdA' / aA' / \varepsilon$

$B \rightarrow bB'$

$B' \rightarrow eB' / \varepsilon$

$\}$

here the start symbol S is A

i Q) $S \rightarrow (L) / a$

$L \rightarrow L, S / S$

ii Q) $E \rightarrow E+E / E*E / a$

iii Q) $A \rightarrow AA\alpha / \beta$.

i Q) here we need not substitute S because substituting S will not lead to left recursion so $S \rightarrow (L) / a$ will be as it is

$L \rightarrow L, S / S$ is a left recursion so

Given	substitution	without left recursion
$L \rightarrow \underbrace{L}\underbrace{,S}_{\alpha_1} / \underbrace{S}_{\beta_1}$	$A = L$	$L \rightarrow SL'$
	$\alpha_1 = ,S$	$A \rightarrow \beta_1 A'$
		$A' \rightarrow \alpha_1 A' / \varepsilon$
	$\beta_1 = S$	$L' \rightarrow ,SL' / \varepsilon$

ii Q)

Given	substitution	without left recursion
$E \rightarrow E\underbrace{+E}_{\alpha_1} / E\underbrace{*E}_{\alpha_2} / \underbrace{a}_{\beta_1}$	$A = E$	$E \rightarrow aE'$
	$\alpha_1 = +E$	
	$\alpha_2 = *E$	$E' \rightarrow +EE' / *EE' / \varepsilon$
	$\beta_1 = a$	

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Elimination of Useless Symbols

$S \to ABCa / bD$

$A \to aA / a$

$B \to bB$

$D \to ab / Ea$

$E \to aC / d$

→ here we can see that there are few useless symbols which we must eliminate using some standard theorem

old variables OV	New Variables NV	production
initially no old variables	the variables generating only terminals are A, D, E our new variables. these new variables will be our old variables in next step	first find only productions generating terminals: $A \to a$, $D \to ab$, $E \to d$ terminal
A, D, E look for these variables in productions and select them	write old variables followed by any new variable: A, D, E, S new var	$S \to aA$, $A \to aA$, $D \to E$ suppose we have not listed $D \to CE$ so we should select it
A, D, E, S now search only for productions with S	no new variables A, D, E, S	no productions —

Now write Grammar,

$G_1 = (V_1, T_1, P_1, S)$

$V_1 = \{S, A, D, E\}$ variables

$T_1 = \{a, d, b\}$ terminals

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$P_1 = \{ \quad S \rightarrow aA$ productions
$A \rightarrow aA / a$
$D \rightarrow Ea / ab$
$E \rightarrow d$
$\}$
~~Start symbol is S~~
Now we need to again filter it

P'	T'	V'
–	–	S start symbol
$S \rightarrow aA$	a	S, A (new var)
$A \rightarrow aA / a$	a	S, A no new var so stop

Grammar $G' = (V', T', P', S)$

$V' = \{S, A\}$ variables
$T' = \{a\}$ terminals
$P' = \{ \quad S \rightarrow aA$ productions
$A \rightarrow aA / a$
$\}$

S is the start symbol
now we have removed all useless production

2) $S \rightarrow aA / a / Bb / cC$
$A \rightarrow aB$
$B \rightarrow a / Aa$
$C \rightarrow CD$
$D \rightarrow ddd$

→

OV	NV	productions
–	S, B, D	$S \rightarrow a$ $B \rightarrow a$ $D \rightarrow ddd$

S, B, D	S, B, D, A	$S \to Bb$ $A \to aB$ $C \to CD$ ✗ C is not listed so don't take
S, B, D, A	S, B, D, A	$S \to aA$ $B \to Aa$
S, B, D, A	S, B, D, A	—

Let Grammar $G_1 = (V_1, T_1, P_1, S)$

$V_1 = \{S, A, B, D\}$

$T_1 = \{a, b, d\}$

$P_1 = \{ \; S \to aA / Bb / a$

$A \to aB$

$B \to Aa / a$

$D \to ddd$

$\}$

S is the start symbol.

Now filter it

P'	T'	V'
—	—	S
$S \to aA/Bb/a$	a, b	S, A, B
$A \to aB$	a, b	S, A, B
$B \to aA/a$	a, b	S, A, B

Let $G_1' = (V', T', P', S)$

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

$T' = \{a, b\}$

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$P' = \{ S \to aA / Bb / a$

$A \to aB$

$B \to Aa / a$

$\}$

S is start symbol

3) $S \to ABa / BC$

$A \to ac / Bcc / a$

$B \to bbc$

$C \to CA$

→

OV	NV	Productions
-	A, B	$A \to ac/a$ $B \to bbc$
A, B	A, B, S	$S \to AB$ $S \to BC$ ✗ not there $A \to Bcc$ $C \to CA$ ✗ not there
A, B, S	A, B, S	-

Let Grammar $G' = (V', T', P', S')$

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

$T' = \{a, b, c\}$

$P' = \{ S \to AB$

$A \to Bcc / ac / a$

$B \to bbc$

$\}$

Now we filter it.

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Elimination of ε - production

1) $S \rightarrow ABCa / bD$

$A \rightarrow BC / b$

$B \rightarrow b / \varepsilon$

$C \rightarrow c / \varepsilon$

$D \rightarrow d$

→

Old variable OV	New Variable NV	Production
-	B, C	$B \rightarrow \varepsilon$ $C \rightarrow \varepsilon$ (Productions having ε)
B, C	A, B, C	$A \rightarrow BC$
A, B, C	A, B, C	(do not select productions having terminals) -

∴ A, B, C are nullable variables

Given production	Production without ε
$S \rightarrow ABCa$	$ABCa / ABa / BCa / ACa / Aa / Ba / Ca / a$
$S \rightarrow bD$	bD / b
$A \rightarrow Bc / b$	$Bc / B / c / b$
$B \rightarrow b / \varepsilon$	b
$C \rightarrow c / \varepsilon$	c
$D \rightarrow d$	d

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Let $G = (V, T, P, S)$
$V = \{S, A, B, C, D\}$
$T = \{a, b, c, d\}$
$P = \{ ABCa / ABa / BCa / ACa / Aa / Ba / Ca / a$
bD / b
BC / B / C / b
b
c
d
}
S is the start stat.

2) $S \rightarrow BAAB$ zero
$A \rightarrow 0A2 / 2A0 / \varepsilon$
$B \rightarrow AB / 1B / \varepsilon$

->

OV	NV	Production
-	A, B	$A \rightarrow \varepsilon$ $B \rightarrow \varepsilon$
A, B	A, B, S	$S \rightarrow BAAB$ $B \rightarrow AB$
A, B, S	A, B, S	-

∴ A, B, S are nullable variables

Given Production	Production without ε
$S \rightarrow BAAB$	dont eliminate terminals ... BAAB / BAA / B / AAB / AA... / AB / BAB / BB
$A \rightarrow 0A2 / 2A0 / \varepsilon$	0A2 / 02 / 2A0 / 20
$B \rightarrow AB / 1B / \varepsilon$	AB / A / B / 1B / 1

let G=(V,T,P,S)
V={A, B, S}
T={0, 1, 2}
P={BAAB/BAA/B/AAB/AA/A/AB/BAB/BB,
OA2/02/2A0/20,
AB/A/B/1B/1
}
T={0, 1, 2}
S is the start state

3) S → XYX
X → 0X/ε
Y → 1Y/ε

→

OV	NV	Production
–	X, Y	X → ε
		Y → ε
X, Y	X, Y, S	S → XYX
X, Y, S	X, Y, S	ε

here X, Y, S are nullable variables.

Given Production	Production without ε
S → XYX	XYX/XY/X/YX/XX/Y
X → 0X	0X/0/X
Y → 1Y	1Y/Y/1

let G=(V,T,P,S)
V={S, X, Y}
T={0, 1}
P={XYX/XY/X/YX/XX/Y,
0X/0/X,

there S is the start state.

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4) S → aAbA
S → SA
A → Y | ε
Y → bY/b

→

OV	NV	Production
–	A	A → ε
A	A	–

here A is the nullable variable

given production	Production without ε
S → aAbA	aAbA/aAb/AbA/ab
S → SA	SA/S/A
A → Y/ε	Y
Y → bY/b	bY/b/Y

production should not be repeated so 'Y' does con...

Let G = (V, T, P, S)
V = {S, A, Y} T = {a, b}
P = { aAbA/aAb/AbA/ab,
SA/S/A,
Y,
bY/Y/b
}

here 'S' is the start state.

5) S → AB
A → aAA/ε
B → bBB/ε

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→

OV	NV	Production
-	A, B	$A \to \varepsilon$ $B \to \varepsilon$
A, B	A, B, S	$S \to AB$
A, B, S	A, B, S	-

∴ Here A, B, S are nullable variables.

Given Production	Production without ε
$S \to AB$	AB/A/B
$A \to aAA/\varepsilon$	aAA/aA/AA.
$B \to bBB/\varepsilon$	bBB/bB/BB

Let $G = (V, T, P, S)$
$V = \{S, A, B\}$ $T = \{a, b\}$
P = { AB/A/B,
aAA/aA/AA,
bBB/bB/BB
}
S = start ~~state~~

(small everywhere

6) $S \to ACB/cbB/Ba$
$A \to da/BC$
$B \to gc/\varepsilon$

→

OV	NV	Production
-	B	$B \to \varepsilon$
B	B	-

here B is the nullable variable

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Given Production	Production without ϵ
$S \rightarrow AcB / cbB / Ba$	$AcB / Ac / cB / A / c / B / cb / bB / Ba / a$
$A \rightarrow da / Bc$	$da / d / Bc$
$B \rightarrow gc / \epsilon$	gc / g

Let $G = (V, T, P, S)$
$V = \{S, A, B\}$
$T = \{a, b, c, d\}$
$P = \{ AcB/Ac/cB/A/c/B/cbB/bB/Ba/a,$
$da/d/Bc,$
gc/g
$\}$

S = start state

Eliminating unit production

1) $S \rightarrow AB$
$A \rightarrow a$
$B \rightarrow C / b$
$C \rightarrow D$
$D \rightarrow E / bC$
$E \rightarrow d / Ab$

→ step 1: Write non-unit production
$S \rightarrow AB$
$A \rightarrow a$
$B \rightarrow b$
$D \rightarrow bC$
$E \rightarrow d / Ab$

unit productions means it tends to a single variable like A, B

step 2: Write unit productions
$B \rightarrow C$ single var
$C \rightarrow D$

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$D \to E$

step3:- Draw dependency graph

$B \to C \to D \to E$

step4:- • $D \to E$ also $E \to d/Ab$

$\therefore D \to d/Ab/bC$

• $C \to D$ also $D \to d/Ab/bC$

$\therefore C \to d/Ab/bC$

• $B \to C$ also $C \to d/Ab/bC$

$\therefore B \to d/Ab/bC/b$

step5:- The final grammar is

$S \to AB$

$A \to a$

$B \to d/Ab/bC/b$

$C \to d/Ab/bC$

$D \to d/Ab/bC$

$E \to d/Ab$

2) $S \to A0/B$

$B \to A/11$, zero so it's not a variable; it's a terminal

$A \to 0/12/B$

→ step1:- non-unit production

$S \to A0$

$B \to 11$

$A \to 0/12$

step2:- unit production

$S \to B$

$B \to A$

$A \to B$

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step 3:- dependency graph.

$$\begin{tikzcd} S \arrow[r] & B \arrow[r] & A \arrow[l, bend left] \end{tikzcd}$$

step 4:-
- $B \rightarrow A$

also $A \rightarrow 0/12/B$ and $B \rightarrow 11$
$\Rightarrow A \rightarrow 0/12/11$.
$\therefore B \rightarrow 0/12/11$

- $S \rightarrow B$ also $B \rightarrow 0/12/11$ and $S \rightarrow AD$
$\therefore S \rightarrow 0/12/11/AD$

- $A \rightarrow B$ also $B \rightarrow 0/12/11$
so $\therefore A \rightarrow 0/12/11$

step 5:- The final grammar is
$S \rightarrow 0/12/11/AD$
$B \rightarrow 0/12/11$
$A \rightarrow 0/12/11$

3) $S \rightarrow Aa/B/Ca$
$B \rightarrow aB/b$
$C \rightarrow Db/D$
$D \rightarrow E/d$
$E \rightarrow ab$

→ step 1:- Non-unit production
$S \rightarrow Aa/Ca$
$B \rightarrow aB/b$
$C \rightarrow Db$
$E \rightarrow ab$

step2:- unit production

S → B

C → D

D → E

step3:- Dependency graph

$S \rightarrow B$

$C \rightarrow D \rightarrow E$

step4:- • since S → B also B → aB/b

∴ S → aB/b/Aa/Ca

• D → E also E → ab

∴ D → ab/d

• C → D also D → ab/d

∴ C → ab/d/Db

step5:- The final grammar is

S → Aa/Ca/aB/b

B → aB/b

C → ab/d/Db

D → ab/d

E → ab

4) S → AB

A → a

B → C/b

C → D

D → E

E → a

→ step 1:- Non-Unit productions

S → AB

A → a

B → b

E → a

step2:- unit productions

B → C

C → D

D → E

step 3:- Dependency graph

B → C → D → E

step 4:- * D → E also E → a ∴ D → a

* C → D also D → a

so ∴ C → a

* B → C also C → a

∴ B → a/b

step 5:- The final grammar is

S → AB

A → a

B → a/b

C → a

D → a

E → a

5) S → S+T/T

T → T*F/F

F → (S)/a   ( ) are terminals

→ step 1:- Non-unit production

S → S+T

T → T*F

F → (S)/a

step 2:- unit production

S → T

T → F

step 3:- dependency graph

S → T → F

step 4:- *T → F also F → (S)/a

∴ T → (S)/a/T*F

• $S \rightarrow T$ also $T \rightarrow (S)/a/T*F$

$\therefore S \rightarrow (S)/a/T*F/S+T$

step 5:- The final grammar is

$S \rightarrow (S)/a/T*F/S+T$

$T \rightarrow (S)/a/T*F$

$F \rightarrow (S)/a$

6) $S \rightarrow A/B/C$

$A \rightarrow aAa/B$

$B \rightarrow bB/bb$

$C \rightarrow aCaa/D$

$D \rightarrow baD/abD/aa$

→ step 1:- non-unit productions

$A \rightarrow aAa$

$B \rightarrow bB/bb$

$C \rightarrow aCaa$

$D \rightarrow baD/abD/aa$

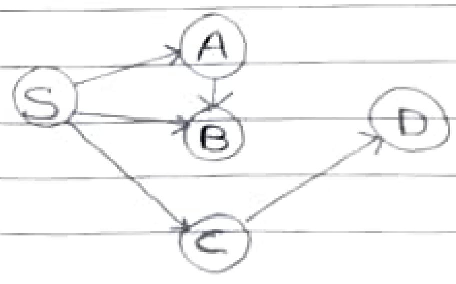
step 2:- unit productions

$S \rightarrow A/B/C$

$A \rightarrow B$

$C \rightarrow D$

step 3:- dependancy graph



step 4:-

* $A \rightarrow B$ also $B \rightarrow bB / bb$

  $\therefore A \rightarrow bB / bb / aAa$

* $C \rightarrow D$ also $D \rightarrow baD / abD / aa$

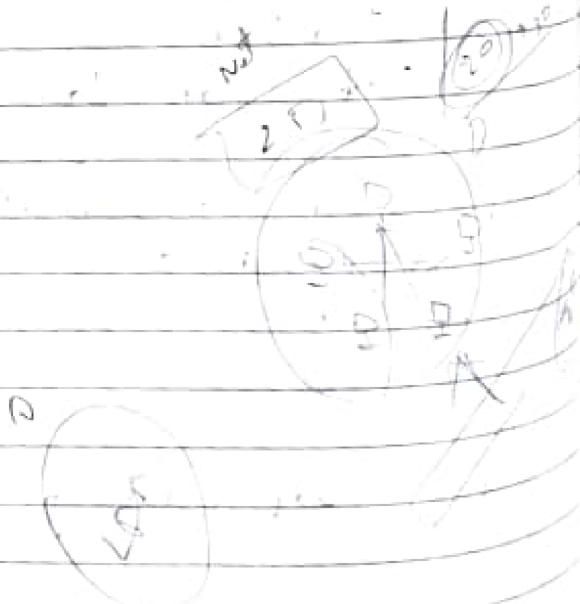
  $\therefore C \rightarrow baD / abD / aa / aCaa$

* $S \rightarrow A / B / C$

  $\therefore S \rightarrow bB / bb / aAa / baD / abD / aa / aCaa$.

step 5:- The final grammar is

$S \rightarrow bB / bb / aAa / baD / abD / aa / aCaa$
$A \rightarrow aAa / bb / bB$
$B \rightarrow bB / bb$
$C \rightarrow aCaa / baD / abD / aa$
$D \rightarrow baD / abD / aa$



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chomsky Normal form (CNF)

step1:- Eliminate the start symbol from right hand side create a new production $S_0 \rightarrow S$ where S_0 is the new start symbol

step2:- Get rid of all ε-productions (Eliminate epsilon (ε) productions)

step3:- Eliminate unit productions

step4:- Eliminate all useless symbols

step5:- Replace long productions by short ones
Ex:- if we have $A \rightarrow BCD$
then we can write $E \rightarrow CD$ and write
new production
$A \rightarrow BE$
chomsky normal form can be only of two forms
$A \rightarrow BC$
$A \rightarrow a$

step6:- move terminals to unit production
Ex:- if we have $A \rightarrow bC$ which is not in CNF so we introduce $B \rightarrow b$ and write as $A \rightarrow BC$

(G)
$S \rightarrow 0A / 1B$
$A \rightarrow 0AA / 1S / 1$
$B \rightarrow 1BB / 0S / 0$

Kavitha

→ first check on right hand side and see if we have start symbol 'S'
here we have it so introduce new production

$S_0 \longrightarrow S$

There is no epsilon (ε) production
There is a unit production $S_0 \longrightarrow S$

$S_0 \longrightarrow 0A/1B$

Now find if there are any useless symbols
There are no useless symbols

Now.

Given Production GP	action taken AT	Resulting Prod RP
$S_0 \rightarrow 0A/1B$ this is not in CNF	$A_0 \rightarrow 0$ $B_0 \rightarrow 1$	$S_0 \rightarrow A_0A/B_0B$ this is in CNF
$S \rightarrow 0A/1B$	$A_0 \rightarrow 0$ $B_0 \rightarrow 1$	$S \rightarrow A_0A/AB$
$A \rightarrow 0AA/1S/1$ ($0AA/1S$ not in CNF, 1 valid CNF)	$A_0 \rightarrow 0$ $B_0 \rightarrow 1$	$A \rightarrow A_0AA/B_0S/1$ $A_0 \rightarrow 0$ $B_0 \rightarrow 1$
$B \rightarrow 1BB/0S/0$	$A_0 \rightarrow 0$ $B_0 \rightarrow 1$	$B \rightarrow B_0BB/A_0S/0$ $A_0 \rightarrow 0$ $B_0 \rightarrow 1$

we get the productions

$S_0 \rightarrow A_0A/B_0B$
$S \rightarrow A_0A/B_0B$
$A \rightarrow \underline{A_0AA}/B_0S/1$ (not in CNF)

$B \rightarrow B_0BB / A_0S / D$ (not in CNF)

$A_0 \rightarrow 0$

$B_0 \rightarrow 1$

again,

GD	AT	RP
$A \rightarrow A_0AA$	$D_0 \rightarrow AA$	$A \rightarrow A_0D_0$ $D_0 \rightarrow AA$
$B_0 \rightarrow B_0BB$	$D_1 \rightarrow BB$	$B \rightarrow B_0D_1$ $D_1 \rightarrow BB$

Now we get, finally we get
write all productions

$A \rightarrow A_0D_0$

$D_0 \rightarrow AA$

$B \rightarrow B_0D_1$

$D_1 \rightarrow BB$

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

$V = \{S_0, S, A, B, A_0, B_0, D_0, D_1\}$

$T = \{0, 1\}$

$P = \{$ ... all productions obtained above $\}$

S_0 is the start state

3) $S \rightarrow aXbX$

$X \rightarrow aY / bY / \varepsilon$

$Y \rightarrow X / c$

→ no S on RHS so no S_0 needed

There is ε production so we get

$S \rightarrow aXbX / aXb / abX / ab$

$X \rightarrow aY / a / bY / b$

$Y \rightarrow X / c$

There is unit production
$Y \rightarrow X$ since $X \rightarrow aY/a/bY/b$
we get

$Y \rightarrow aY/a/bY/b/a$

There is no useless symbol
so now,

Given Production GP	action taken AT	Resulting Production RP
$S \rightarrow aXbX/aXb/abX$ $/ab$	$A_0 \rightarrow a$ $B_0 \rightarrow b$	$S \rightarrow A_0XB_0X/$ $A_0XB/A_0B_0X/A_0B_0$ $A_0 \rightarrow a$ $B_0 \rightarrow b$
$X \rightarrow aY/a/bY/b$	$A_0 \rightarrow a$ $B_0 \rightarrow b$	$X \rightarrow A_0Y/a/B_0Y/b$ $A_0 \rightarrow a$ $B_0 \rightarrow b$
$Y \rightarrow aY/a/bY/b/c$	$A_0 \rightarrow a$ $B_0 \rightarrow b$	$Y \rightarrow A_0Y/a/B_0Y/$ b/c $A_0 \rightarrow a$ $B_0 \rightarrow b$

we got,
$S \rightarrow A_0XB_0X / A_0XB_0 / A_0B_0X / A_0B_0$ not in CNF
$X \rightarrow A_0Y/a/B_0Y/b$
$Y \rightarrow A_0Y/a/B_0Y/b/c$ these are in CNF
$A_0 \rightarrow a$
$B_0 \rightarrow b$

again.

GP	AT	RP
$S \to A_0XB_0X / A_0XB_0$ $/ A_0B_0X$	$D_0 \to B_0X$ $D_1 \to XB_0$	$S \to A_0XD_0 / A_0D_1 /$ A_0D_0 $D_0 \to B_0X$ $D_1 \to XB_0$ not in CNF so
$S \to A_0XD_0$	$D_2 \to XD_0$	$S \to A_0D_2$ $D_2 \to XD_0$ all are in CNF

finally, we get

$S \to A_0D_2 / A_0D_1 / A_0D_0 / A_0B_0$
$X \to A_0Y / a / B_0Y / b$
$Y \to A_0Y / a / B_0Y / b / c$
$A_0 \to a$
$B_0 \to b$
$D_0 \to B_0X$
$D_1 \to XB_0$
$D_2 \to XD_0$

Let $G = (V, T, P, S)$
$V = \{S, X, Y, A_0, B_0, D_0, D_1, D_2\}$
$T = \{a, b, c\}$
$P = \{ \ldots$
$\ldots$
$\}$

S is the start state

3a) $S \to a / aA / B / C$
$A \to aB / \varepsilon$
$B \to aA / \varepsilon$
$C \to cCD$
$D \to ddd$

4Q) $S \rightarrow ABC / BaB$
$A \rightarrow aA / BaC / aaa$
$B \rightarrow bBb / a / D$
$C \rightarrow CA / AC$
$D \rightarrow \varepsilon$

5Q) $S \rightarrow 0A0 / 1B1 / BB$
$A \rightarrow C$
$B \rightarrow S / A$
$C \rightarrow S$