

# **Introduction to Theoretical Computer Science**

**Exercise tasks**

**Preparation for final exam – part 2**

**Faculty of Electrical Engineering and Computing  
University of Zagreb**



## Task 31

- Construct grammar that generates sequences in the following format:  $a^i b^j c^k d^i e^j$  where  $i, j, k \geq 1$ .

## Task 31

- Construct grammar that generates sequences in the following format:  $a^i b^j c^k d^l e^m$  where  $i, j, k \geq 1$ .

Unrestricted grammar:

## Task 31

- Construct grammar that generates sequences in the following format:  $a^i b^j c^k d^l e^m$  where  $i, j, k \geq 1$ .

Unrestricted grammar:

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

## Task 31

- Construct grammar that generates sequences in the following format:  $a^i b^j c^k d^l e^m$  where  $i, j, k \geq 1$ .

Unrestricted grammar:

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

Production format:

## Task 31

- Construct grammar that generates sequences in the following format:  $a^i b^j c^k d^l e^m$  where  $i, j, k \geq 1$ .

Unrestricted grammar:

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

Production format:

$\alpha \rightarrow \beta$      $\alpha, \beta$  sequences of terminal and nonterminal symbols

## Task 31

- Construct grammar that generates sequences in the following format:  $a^i b^j c^k d^l e^m$  where  $i, j, k, l, m \geq 1$ .

Unrestricted grammar:

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

Production format:

$\alpha \rightarrow \beta$      $\alpha, \beta$  sequences of terminal and nonterminal symbols  
 $\alpha \neq \epsilon$

# Task 31

Sequence format:

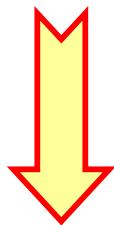
## Task 31

Sequence format:

$$a^i b^j c^k d^l e^m$$

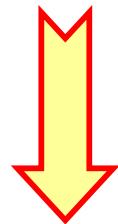
## Task 31

Sequence format:

$$a^i b^j c^k d^l e^m$$


## Task 31

Sequence format:

$$a^i b^j c^k d^l e^m$$


$$\#(a) = \#(d)$$

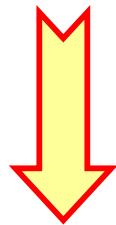
$$\#(b) = \#(e)$$

$$\#(c)$$

## Task 31

Sequence format:

$$a^i b^j c^k d^l e^m \quad i, j, k, l, m \geq 1$$



$$\#(a) = \#(d)$$

$$\#(b) = \#(e)$$

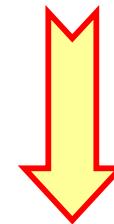
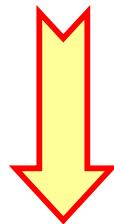
$$\#(c)$$

## Task 31

Sequence format:

$$a^i b^j c^k d^l e^m$$

$$i, j, k \geq 1$$



$$\#(a) = \#(d)$$

$$\#(b) = \#(e)$$

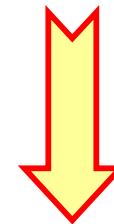
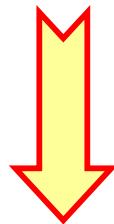
$$\#(c)$$

## Task 31

Sequence format:

$$a^i b^j c^k d^l e^m$$

$$i, j, k \geq 1$$



$$\#(a) = \#(d)$$

There is no generating of an empty sequence.

$$\#(b) = \#(e)$$

$$\#(c)$$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

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

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$S \rightarrow a b c d e$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$S \rightarrow a b c d e$   
 $S \rightarrow a \quad b \quad c \quad d \quad e$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$S \rightarrow a b c d e$

$S \rightarrow a \ b \ c \ d \ e$

$S \rightarrow a A b B c C d e$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

$S \rightarrow a A b B c C d e$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

$S \rightarrow a A b B c C d e$

$A \rightarrow \epsilon$

$B \rightarrow \epsilon$

$C \rightarrow \epsilon$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

$S \rightarrow a A b B c C d e$

$A \rightarrow a A$

$B \rightarrow b B$

$C \rightarrow c C$

$A \rightarrow \epsilon$

$B \rightarrow \epsilon$

$C \rightarrow \epsilon$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

$S \rightarrow a A b B c C d e$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$B \rightarrow b B$

$B \rightarrow \epsilon$

$C \rightarrow c C$

$C \rightarrow \epsilon$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

$S \rightarrow a A b B c C d e$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$C \rightarrow c C$

$C \rightarrow \epsilon$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

$S \rightarrow a A b B c C d e$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$C \rightarrow c C$

$C \rightarrow \epsilon$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

$S \rightarrow a A b B c C d e \rightarrow a a A D b B c C d e$

$A \rightarrow a A D$

$B \rightarrow b B E$

$C \rightarrow c C$

$A \rightarrow \epsilon$

$B \rightarrow \epsilon$

$C \rightarrow \epsilon$

## Task 31

Grammar construction:

 $a^i b^j c^k d^l e^m$  $V = \{ A, B, C, D, E, S \}$  $T = \{ a, b, c, d, e \}$ 

S initial nonterminal symbol

 $S \rightarrow a A b B c C d e \rightarrow a a A \underline{D} b B c C d e$  $A \rightarrow a A D$  $B \rightarrow b B E$  $C \rightarrow c C$  $A \rightarrow \epsilon$  $B \rightarrow \epsilon$  $C \rightarrow \epsilon$  $D b \rightarrow b D$

## Task 31

Grammar construction:

 $a^i b^j c^k d^l e^m$  $V = \{ A, B, C, D, E, S \}$  $T = \{ a, b, c, d, e \}$ 

S initial nonterminal symbol

 $S \rightarrow a A b B c C d e \rightarrow a a A \underline{D} b B c C d e$  $A \rightarrow a A D$  $B \rightarrow b B E$  $C \rightarrow c C$  $A \rightarrow \epsilon$  $B \rightarrow \epsilon$  $C \rightarrow \epsilon$  $D b \rightarrow b D$  $D c \rightarrow c D$

## Task 31

Grammar construction:

 $a^i b^j c^k d^l e^m$  $V = \{ A, B, C, D, E, S \}$  $T = \{ a, b, c, d, e \}$ 

S initial nonterminal symbol

 $S \rightarrow a A b B c C d e \rightarrow a a A \underline{D} b B c C d e$  $A \rightarrow a A D$  $B \rightarrow b B E$  $C \rightarrow c C$  $A \rightarrow \epsilon$  $B \rightarrow \epsilon$  $C \rightarrow \epsilon$  $D b \rightarrow b D$  $D c \rightarrow c D$  $D d \rightarrow d D$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

$S \rightarrow a A b B c C d e \rightarrow a a A \underline{D} b B c C d e$

$A \rightarrow a A D$

$B \rightarrow b B E$

$C \rightarrow c C$

$A \rightarrow \epsilon$

$B \rightarrow \epsilon$

$C \rightarrow \epsilon$

$D b \rightarrow b D$

$E c \rightarrow c E$

$D c \rightarrow c D$

$E d \rightarrow d E$

$D d \rightarrow d d$

## Task 31

Grammar construction:

$a^i b^j c^k d^l e^m$

$V = \{ A, B, C, D, E, S \}$

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

S initial nonterminal symbol

$S \rightarrow a A b B c C d e$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$C \rightarrow c C$

$C \rightarrow \epsilon$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d D$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e E$



## Task 31

Example of generating sequence  $aabbcccddee$ :

S

-

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

S

-

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence *aabbccddeee*:

S → aAbBcCde

S → a A b B c C d e

C → c C

C → ε

A → a A D

A → ε

D b → b D

D c → c D

D d → d d

B → b B E

B → ε

E c → c E

E d → d E

E e → e e



## Task 31

Example of generating sequence *aabbccddeee*:

S → aA**A**bBcC**C**d**e**

S → a A b B c C d e

C → c C

C → ε

A → a A D

A → ε

D b → b D

D c → c D

D d → d d

B → b B E

B → ε

E c → c E

E d → d E

E e → e e



## Task 31

Example of generating sequence *aabbccddeee*:

S → aAbBcCde → aaAD**B**cCde

$S \rightarrow a A b B c C d e$

$C \rightarrow c C$

$C \rightarrow \epsilon$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d d$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

## Task 31

Example of generating sequence  $aabbcccddee$ :

S → aAbBcCde → aaADbBcCde

$S \rightarrow a A b B c C d e$

$C \rightarrow c C$

$C \rightarrow \epsilon$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d d$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$



## Task 31

Example of generating sequence  $aabbcccddee$ :

S → aAbBcCde → aaAD**B**cCde

$S \rightarrow a A b B c C d e$

$C \rightarrow c C$

$C \rightarrow \epsilon$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d d$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

## Task 31

Example of generating sequence  $aabbcccddee$ :

S → aAbBcCde → aaAD**B**cCde → aaD**B**cCde

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

S → aAbBcCde → aaAD**B**cCde → aaD**B**cCde

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$

## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}BEcCde$

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aaA\underline{DbBcCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbBEcCde} \rightarrow aaDb\underline{bbB}\epsilon$

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}B\underline{E}cCde$

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}bEcCde$

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de$

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$

$S \rightarrow a A b B c C d e$

$C \rightarrow c C$

$C \rightarrow \epsilon$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d d$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}B\underline{E}cCde \rightarrow aaDb\underline{b}B\underline{E}c\underline{C}de \rightarrow aaDb\underline{b}B\underline{E}c\underline{C}de$

$$S \rightarrow a A b B c C d e$$

$$C \rightarrow c C$$

$$C \rightarrow \epsilon$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$   
 $\rightarrow aaDb\underline{b}Ecde$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C \rightarrow c C \\ C \rightarrow \epsilon \end{aligned}$$

$$\begin{aligned} A \rightarrow a A D \\ A \rightarrow \epsilon \end{aligned}$$

$$\begin{aligned} D b \rightarrow b D \\ D c \rightarrow c D \\ D d \rightarrow d d \end{aligned}$$

$$\begin{aligned} B \rightarrow b B E \\ B \rightarrow \epsilon \end{aligned}$$

$$\begin{aligned} E c \rightarrow c E \\ E d \rightarrow d E \\ E e \rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$   
 $\rightarrow aaDb\underline{b}Ec\underline{C}de$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$\begin{aligned} A &\rightarrow a A D \\ A &\rightarrow \epsilon \end{aligned}$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$\begin{aligned} B &\rightarrow b B E \\ B &\rightarrow \epsilon \end{aligned}$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$

## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}B\underline{E}cCde \rightarrow aaDb\underline{b}B\underline{E}c\underline{C}de \rightarrow aaDb\underline{b}B\underline{E}c\underline{C}de$   
 $\rightarrow aaDb\underline{b}B\underline{E}c\underline{C}de \rightarrow aaDb\underline{b}B\underline{E}c\underline{C}de$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$   
 $\rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDbbcEcde$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$   
 $\rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$   
 $\rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{bc}Ecde \rightarrow aaDb\underline{bc}Ecde \rightarrow aaDb\underline{bcc}Ede$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$   
 $\rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{bc}Ecde \rightarrow aaDb\underline{bc}Ecde \rightarrow aaDb\underline{bcc}Ede$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C \rightarrow c C \\ C \rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b \rightarrow b D \\ D c \rightarrow c D \\ D d \rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c \rightarrow c E \\ E d \rightarrow d E \\ E e \rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}EcCde \rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{b}Ec\underline{C}de$   
 $\rightarrow aaDb\underline{b}Ec\underline{C}de \rightarrow aaDb\underline{bc}Ecde \rightarrow aaDb\underline{bc}Ecde \rightarrow aaDb\underline{bcc}Ede$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

S → aAbBcCde → aaADbBcCde → aaDbBcCde  
→ aaDbbBEcCde → aaDbbEcCde → aaDbbEccCde  
→ aaDbbEcde → aaDbbbcEcde → aaDbbbccEde  
→ aaDbbbccdEe

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$\begin{aligned} A &\rightarrow a A D \\ A &\rightarrow \epsilon \end{aligned}$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$\begin{aligned} B &\rightarrow b B E \\ B &\rightarrow \epsilon \end{aligned}$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aa\underline{AdBbCcCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbBEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCcCde}$   
 $\rightarrow aaDb\underline{bbEcCcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe}$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

S → aAbBcCde → aaADbBcCde → aaDbBcCde  
→ aaDbbBEcCde → aaDbbEcCde → aaDbbEccCde  
→ aaDbbEcde → aaDbbcEde → aaDbbccEde  
→ aaDbbccdEe

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aa\underline{AdBbCcCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbBEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCcCde}$   
 $\rightarrow aaDb\underline{bbEcCcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe} \rightarrow aaDb\underline{bbccddee}$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aa\underline{AdBbCcCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbBEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCcCde}$   
 $\rightarrow aaDb\underline{bbEcCcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe} \rightarrow aaDb\underline{bbccdee}$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}\underline{B}EcCde \rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bEc\underline{c}Cde$   
 $\rightarrow aaDb\underline{b}bEc\underline{c}de \rightarrow aaDb\underline{b}bcEcde \rightarrow aaDb\underline{b}bcEde$   
 $\rightarrow aaDb\underline{b}bccdEe \rightarrow aaDb\underline{b}bccdee$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b &\rightarrow b D \\ D c &\rightarrow c D \\ D d &\rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c &\rightarrow c E \\ E d &\rightarrow d E \\ E e &\rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}\underline{B}EcCde \rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bEc\underline{C}de$   
 $\rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bcEcde \rightarrow aaDb\underline{b}bcEcde$   
 $\rightarrow aaDb\underline{b}bccdEe \rightarrow aaDb\underline{b}bccdEe \rightarrow aabDbccdee$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C \rightarrow c C \\ C \rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}\underline{B}EcCde \rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bEc\underline{C}de$   
 $\rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bcEcde \rightarrow aaDb\underline{b}bcEcde$   
 $\rightarrow aaDb\underline{b}bccdEe \rightarrow aaDb\underline{b}bccdEe \rightarrow aabDbccdee$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}\underline{B}EcCde \rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bEc\underline{c}Cde$   
 $\rightarrow aaDb\underline{b}bEc\underline{c}de \rightarrow aaDb\underline{b}bcEcde \rightarrow aaDb\underline{b}bcEde$   
 $\rightarrow aaDb\underline{b}bccdEe \rightarrow aaDb\underline{b}bccdee \rightarrow aab\underline{D}bccdee$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}\underline{B}EcCde \rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bEc\underline{C}de$   
 $\rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bcEcde \rightarrow aaDb\underline{b}bcEcde$   
 $\rightarrow aaDb\underline{b}bccdEe \rightarrow aaDb\underline{b}bccddee \rightarrow aab\underline{D}bccddee$   
 $\rightarrow aabb\underline{D}ccddee$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C \rightarrow c C \\ C \rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow a\underline{A}bBcCde \rightarrow aa\underline{A}DbBcCde \rightarrow aaDb\underline{B}cCde$   
 $\rightarrow aaDb\underline{b}\underline{B}EcCde \rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bEc\underline{C}de$   
 $\rightarrow aaDb\underline{b}bEc\underline{C}de \rightarrow aaDb\underline{b}bcEcde \rightarrow aaDb\underline{b}bcEcde$   
 $\rightarrow aaDb\underline{b}bccdEe \rightarrow aaDb\underline{b}bccddee \rightarrow aab\underline{D}bccddee$   
 $\rightarrow aabbDccdee$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbcccddee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aa\underline{AdBbCcCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbBEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCcCde}$   
 $\rightarrow aaDb\underline{bbEcCcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe} \rightarrow aaDb\underline{bbccdee} \rightarrow aab\underline{Dbccdee}$   
 $\rightarrow aabb\underline{Dccdee}$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C \rightarrow c C \\ C \rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aa\underline{AdBbCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCde}$   
 $\rightarrow aaDb\underline{bbEcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe} \rightarrow aaDb\underline{bbccdee} \rightarrow aab\underline{Dbccdee}$   
 $\rightarrow aabb\underline{Dccdee} \rightarrow aabb\underline{cDcdee}$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$S \rightarrow aAbBcCde \rightarrow aaAdbBcCde \rightarrow aaDbBcCde$   
 $\rightarrow aaDbBbBEcCde \rightarrow aaDbBbEcCde \rightarrow aaDbBbEcCcCde$   
 $\rightarrow aaDbBbEcCcde \rightarrow aaDbBbcEcde \rightarrow aaDbBbcEcde$   
 $\rightarrow aaDbBbccdEe \rightarrow aaDbBccdee \rightarrow aabDbccdee$   
 $\rightarrow aabbDccdee \rightarrow aabbcDcdee$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C \rightarrow c C \\ C \rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b \rightarrow b D \\ D c \rightarrow c D \\ D d \rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c \rightarrow c E \\ E d \rightarrow d E \\ E e \rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$S \rightarrow aAbBcCde \rightarrow aaAdbBcCde \rightarrow aaDbBcCde$   
 $\rightarrow aaDbBbBEcCde \rightarrow aaDbBbEcCde \rightarrow aaDbBbEcCcCde$   
 $\rightarrow aaDbBbEcCcde \rightarrow aaDbBbcEcde \rightarrow aaDbBbcEcde$   
 $\rightarrow aaDbBbccdEe \rightarrow aaDbBccdee \rightarrow aabDbccdee$   
 $\rightarrow aabbDccdee \rightarrow aabbcDcdee$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C \rightarrow c C \\ C \rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b \rightarrow b D \\ D c \rightarrow c D \\ D d \rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c \rightarrow c E \\ E d \rightarrow d E \\ E e \rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$S \rightarrow aAbBcCde \rightarrow aaAdBbCcCde \rightarrow aaDbBcCde$   
 $\rightarrow aaDbbBEcCde \rightarrow aaDbbEcCde \rightarrow aaDbbEccCde$   
 $\rightarrow aaDbbEccde \rightarrow aaDbbcEcde \rightarrow aaDbbccEde$   
 $\rightarrow aaDbbccdEe \rightarrow aaDbbccdee \rightarrow aabDbccdee$   
 $\rightarrow aabbDccdee \rightarrow aabbcDcdee \rightarrow aabbccDdee$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C \rightarrow c C \\ C \rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aa\underline{AdBbCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCde}$   
 $\rightarrow aaDb\underline{bbEcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe} \rightarrow aaDb\underline{bbccdee} \rightarrow aab\underline{Dbccdee}$   
 $\rightarrow aabb\underline{Dccdee} \rightarrow aabb\underline{cDcdee} \rightarrow aabbcc\underline{Ddee}$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C &\rightarrow c C \\ C &\rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aa\underline{AdBbCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCde}$   
 $\rightarrow aaDb\underline{bbEcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe} \rightarrow aaDb\underline{bbccdee} \rightarrow aab\underline{Dbccdee}$   
 $\rightarrow aabb\underline{Dccdee} \rightarrow aabb\underline{cDccdee} \rightarrow aabbcc\underline{Ddee}$

$S \rightarrow a A b B c C d e$

$C \rightarrow c C$   
 $C \rightarrow \epsilon$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$D b \rightarrow b D$   
 $D c \rightarrow c D$   
 $D d \rightarrow d d$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$E c \rightarrow c E$   
 $E d \rightarrow d E$   
 $E e \rightarrow e e$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aa\underline{AdBbCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCde}$   
 $\rightarrow aaDb\underline{bbEcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe} \rightarrow aaDb\underline{bbccdee} \rightarrow aab\underline{Dbccdee}$   
 $\rightarrow aabb\underline{Dccdee} \rightarrow aabb\underline{bcDcdee} \rightarrow aabbcc\underline{Ddee}$   
 $\rightarrow aabbcc\underline{ddee}$

$$S \rightarrow a A b B c C d e$$

$$\begin{aligned} C \rightarrow c C \\ C \rightarrow \epsilon \end{aligned}$$

$$A \rightarrow a A D$$

$$A \rightarrow \epsilon$$

$$\begin{aligned} D b \rightarrow b D \\ D c \rightarrow c D \\ D d \rightarrow d d \end{aligned}$$

$$B \rightarrow b B E$$

$$B \rightarrow \epsilon$$

$$\begin{aligned} E c \rightarrow c E \\ E d \rightarrow d E \\ E e \rightarrow e e \end{aligned}$$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aaA\underline{DbBcCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbBEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCde}$   
 $\rightarrow aaDb\underline{bbEcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe} \rightarrow aaDb\underline{bbccdee} \rightarrow aab\underline{Dbccdee}$   
 $\rightarrow aabb\underline{Dccdee} \rightarrow aabb\underline{bcDcdee} \rightarrow aabbcc\underline{Ddee}$   
 $\rightarrow aabbccddeee$

$S \rightarrow a A b B c C d e$

$C \rightarrow c C$   
 $C \rightarrow \epsilon$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$D b \rightarrow b D$   
 $D c \rightarrow c D$   
 $D d \rightarrow d d$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$E c \rightarrow c E$   
 $E d \rightarrow d E$   
 $E e \rightarrow e e$



## Task 31

Example of generating sequence  $aabbccddeee$ :

$\underline{S} \rightarrow aA\underline{bBcCde} \rightarrow aa\underline{AdBbCde} \rightarrow aaDb\underline{BcCde}$   
 $\rightarrow aaDb\underline{bbBEcCde} \rightarrow aaDb\underline{bbEcCde} \rightarrow aaDb\underline{bbEcCcCde}$   
 $\rightarrow aaDb\underline{bbEcCcde} \rightarrow aaDb\underline{bbcEcde} \rightarrow aaDb\underline{bbccEde}$   
 $\rightarrow aaDb\underline{bbcccdEe} \rightarrow aaDb\underline{bbccdee} \rightarrow aab\underline{Dbccdee}$   
 $\rightarrow aabb\underline{Dccdee} \rightarrow aabb\underline{bcDcdee} \rightarrow aabbcc\underline{Ddee}$   
 $\rightarrow \mathbf{aabbccddeee}$

$S \rightarrow a A b B c C d e$

$C \rightarrow c C$   
 $C \rightarrow \epsilon$

$A \rightarrow a A D$

$A \rightarrow \epsilon$

$D b \rightarrow b D$   
 $D c \rightarrow c D$   
 $D d \rightarrow d d$

$B \rightarrow b B E$

$B \rightarrow \epsilon$

$E c \rightarrow c E$   
 $E d \rightarrow d E$   
 $E e \rightarrow e e$



## Task 32

- Transform the given unrestricted grammar into a context-sensitive grammar.

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

$$B \rightarrow b B E$$

$$A \rightarrow \epsilon$$

$$B \rightarrow \epsilon$$

$$C \rightarrow c C$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$C \rightarrow \epsilon$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

## Task 32

- Transform the given unrestricted grammar into a context-sensitive grammar.

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

$$B \rightarrow b B E$$

$$A \rightarrow \epsilon$$

$$B \rightarrow \epsilon$$

$$C \rightarrow c C$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$C \rightarrow \epsilon$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

Transformation method:

## Task 32

- Transform the given unrestricted grammar into a context-sensitive grammar.

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

$$B \rightarrow b B E$$

$$A \rightarrow \epsilon$$

$$B \rightarrow \epsilon$$

$$C \rightarrow c C$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$C \rightarrow \epsilon$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

Transformation method:

All nonterminal symbols have to be grouped with a terminal symbol.

## Task 32

Productions of *context-sensitive grammar*:

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

$$B \rightarrow b B E$$

$$A \rightarrow \epsilon$$

$$B \rightarrow \epsilon$$

$$C \rightarrow c C$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$C \rightarrow \epsilon$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

$$B \rightarrow b B E$$

$$A \rightarrow \epsilon$$

$$B \rightarrow \epsilon$$

$$C \rightarrow c C$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$C \rightarrow \epsilon$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$   $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

$$B \rightarrow b B E$$

$$A \rightarrow \epsilon$$

$$B \rightarrow \epsilon$$

$$C \rightarrow c C$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$C \rightarrow \epsilon$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

$$B \rightarrow b B E$$

$$A \rightarrow \epsilon$$

$$B \rightarrow \epsilon$$

$$C \rightarrow c C$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$C \rightarrow \epsilon$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$   $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$   $\beta \neq \varepsilon$

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

$$B \rightarrow b B E$$

$$A \rightarrow \varepsilon$$

$$B \rightarrow \varepsilon$$

$$C \rightarrow c C$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$C \rightarrow \varepsilon$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

~~$$A \rightarrow \varepsilon$$~~

$$B \rightarrow b B E$$

~~$$B \rightarrow \varepsilon$$~~

$$C \rightarrow c C$$

~~$$C \rightarrow \varepsilon$$~~

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

~~$$A \rightarrow \varepsilon$$~~

$$[aA] \rightarrow a$$

$$B \rightarrow b B E$$

~~$$B \rightarrow \varepsilon$$~~

$$C \rightarrow c C$$

~~$$C \rightarrow \varepsilon$$~~

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d D$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e E$$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

~~$$A \rightarrow \varepsilon$$~~  
$$[aA] \rightarrow a$$

$$B \rightarrow b B E$$

~~$$B \rightarrow \varepsilon$$~~

$$C \rightarrow c C$$

~~$$C \rightarrow \varepsilon$$~~

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d D$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e E$$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow a A b B c C d e$$

$$A \rightarrow a A D$$

~~$$A \rightarrow \varepsilon$$~~  
$$[aA] \rightarrow a$$

$$B \rightarrow b B E$$

~~$$B \rightarrow \varepsilon$$~~  
$$[bB] \rightarrow b$$

$$C \rightarrow c C$$

~~$$C \rightarrow \varepsilon$$~~

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d D$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e E$$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$S \rightarrow a A b B c C d e$

$A \rightarrow a A D$

$B \rightarrow b B E$

~~$A \rightarrow \varepsilon$~~

$[aA] \rightarrow a$

~~$B \rightarrow \varepsilon$~~

$[bB] \rightarrow b$

$C \rightarrow c C$

~~$C \rightarrow \varepsilon$~~

$[cC] \rightarrow c$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d D$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e E$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta, |\beta| \geq |\alpha|, \alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2, \beta \neq \varepsilon$

~~$S \rightarrow aA bB cC d e$~~

$S \rightarrow [aA] [bB] [cC] d e$

$A \rightarrow a A D$

~~$A \rightarrow \varepsilon$~~   
 $[aA] \rightarrow a$

$B \rightarrow b B E$

~~$B \rightarrow \varepsilon$~~   
 $[bB] \rightarrow b$

$C \rightarrow c C$

~~$C \rightarrow \varepsilon$~~

$[cC] \rightarrow c$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d D$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta, |\beta| \geq |\alpha|, \alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2, \beta \neq \epsilon$

~~$S \rightarrow aA bB cC d e$~~

$S \rightarrow [aA] [bB] [cC] d e$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$B \rightarrow b B E$

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$C \rightarrow c C$

~~$C \rightarrow \epsilon$~~

$[cC] \rightarrow c$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d D$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

~~$S \rightarrow aA bB cC d e$~~

$S \rightarrow [aA] [bB] [cC] d e$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$[bB] \rightarrow b [bBE]$

~~$B \rightarrow b B E$~~

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$C \rightarrow c C$

~~$C \rightarrow \epsilon$~~

$[cC] \rightarrow c$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d D$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta, |\beta| \geq |\alpha|, \alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2, \beta \neq \epsilon$

~~$S \rightarrow aA bB cC d e$~~

~~$S \rightarrow [aA] [bB] [cC] d e$~~

$[cC] \rightarrow c[cC]$

~~$C \rightarrow c C$~~

~~$C \rightarrow \epsilon$~~

$[cC] \rightarrow c$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$[bB] \rightarrow b [bBE]$

~~$B \rightarrow b B E$~~

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d D$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

~~$S \rightarrow aA bB cC d e$~~

~~$S \rightarrow [aA] [bB] [cC] d e$~~

$[cC] \rightarrow c[cC]$

~~$C \rightarrow c C$~~

~~$C \rightarrow \epsilon$~~

$[cC] \rightarrow c$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$[bB] \rightarrow b [bBE]$

~~$B \rightarrow b B E$~~

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

$S \rightarrow [aA] [bB] [cC] d e$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

~~$S \rightarrow aA bB cC d e$~~

~~$S \rightarrow [aA] [bB] [cC] d e$~~

$[cC] \rightarrow c[cC]$

~~$C \rightarrow c C$~~

~~$C \rightarrow \epsilon$~~

$[cC] \rightarrow c$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$[bB] \rightarrow b [bBE]$

~~$B \rightarrow b B E$~~

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

$S \rightarrow \underline{[aA]} \underline{[bB]} \underline{[cC]} d e$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

~~$S \rightarrow aA bB cC d e$~~

~~$S \rightarrow [aA] [bB] [cC] d e$~~

$[cC] \rightarrow c[cC]$

~~$C \rightarrow cC$~~

~~$C \rightarrow \epsilon$~~

~~$[cC] \rightarrow c$~~

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d D$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$[bB] \rightarrow b [bBE]$

~~$B \rightarrow b B E$~~

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

$S \rightarrow [aA] [bB] [cC] d e \rightarrow a [aAD] b [bBE] c [cC] d e$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

~~$S \rightarrow aAbBcCd\epsilon$~~

~~$S \rightarrow [aA] [bB] [cC] d \epsilon$~~

$[cC] \rightarrow c[cC]$

~~$C \rightarrow cC$~~

~~$C \rightarrow \epsilon$~~

$[cC] \rightarrow c$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d D$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$[bB] \rightarrow b [bBE]$

~~$B \rightarrow b B E$~~

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

$S \rightarrow [aA] [bB] [cC] d \epsilon \rightarrow a [aAD] b [bBE] c [cC] d \epsilon$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

~~$S \rightarrow aA bB cC d e$~~

~~$S \rightarrow [aA] [bB] [cC] d e$~~

$[cC] \rightarrow c[cC]$

~~$C \rightarrow c C$~~

~~$C \rightarrow \epsilon$~~

$[cC] \rightarrow c$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$[bB] \rightarrow b [bBE]$

~~$B \rightarrow b B E$~~

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

$[aAD] b \rightarrow [aA] [Db]$

$S \rightarrow [aA] [bB] [cC] d e \rightarrow a [aAD] b [bBE] c [cC] d e$   
 $\rightarrow a [aA] [Db] [bBE] c [cC] d e$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta, |\beta| \geq |\alpha|, \alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2, \beta \neq \epsilon$

~~$S \rightarrow aA bB cC d e$~~

~~$S \rightarrow [aA] [bB] [cC] d e$~~

$[cC] \rightarrow c[cC]$

~~$C \rightarrow c C$~~

~~$C \rightarrow \epsilon$~~

$[cC] \rightarrow c$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$[bB] \rightarrow b [bBE]$

~~$B \rightarrow b B E$~~

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$E c \rightarrow c E$

$E d \rightarrow d E$

$E e \rightarrow e e$

$D b \rightarrow b D$

$D c \rightarrow c D$

$D d \rightarrow d D$

$[aAD] b \rightarrow [aA] [Db]$

$S \rightarrow [aA] [bB] [cC] d e \rightarrow a [aAD] b [bBE] c [cC] d e$   
 $\rightarrow a [aA] [Db] [bBE] c [cC] d e$

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta, |\beta| \geq |\alpha|, \alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2, \beta \neq \epsilon$

~~$S \rightarrow aA bB cC d e$~~

~~$S \rightarrow [aA] [bB] [cC] d e$~~

$[cC] \rightarrow c[cC]$

~~$C \rightarrow c C$~~

~~$C \rightarrow \epsilon$~~

$[cC] \rightarrow c$

$[aA] \rightarrow a [aAD]$

~~$A \rightarrow a A D$~~

~~$A \rightarrow \epsilon$~~

$[aA] \rightarrow a$

$[bB] \rightarrow b [bBE]$

~~$B \rightarrow b B E$~~

~~$B \rightarrow \epsilon$~~

$[bB] \rightarrow b$

$[aAD] b \rightarrow [aA] [Db]$        $[bBE] c \rightarrow [bB] [Ec]$

$S \rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e$

$\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a [aA] [Db] [bB] [Ec] [cC] d e$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$S \rightarrow [aA] [bB] [cC] d e$        $[aA] \rightarrow a [aAD]$        $[bB] \rightarrow b [bBE]$

$[aA] \rightarrow a$        $[bB] \rightarrow b$

$[cC] \rightarrow c [cC]$        $D b \rightarrow b D$        $E c \rightarrow c E$

$[cC] \rightarrow c$        $D c \rightarrow c D$        $E d \rightarrow d E$

$D d \rightarrow d d$        $E e \rightarrow e e$

$[aAD] b \rightarrow [aA] [Db]$        $[bBE] c \rightarrow [bB] [Ec]$

$S \rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e$   
 $\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a [aA] [Db] [bB] [Ec] [cC] d e$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$[cC] \rightarrow c [cC]$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$[cC] \rightarrow c$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$\begin{aligned} S \rightarrow & [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e \\ \rightarrow & a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e \end{aligned}$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$[cC] \rightarrow c [cC]$$

$$D b \rightarrow b D$$

$$E c \rightarrow c E$$

$$[cC] \rightarrow c$$

$$D c \rightarrow c D$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$E e \rightarrow e e$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$\begin{aligned} S &\rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e \\ &\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e \\ &\rightarrow a a [Db] b [Ec] c d e \end{aligned}$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$[Db] \rightarrow [bD]$$

~~$$D b \rightarrow b D$$~~

$$D c \rightarrow c D$$

$$D d \rightarrow d d$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$\begin{aligned} S &\rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e \\ &\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e \\ &\rightarrow a a [Db] b [Ec] c d e \end{aligned}$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$[Db] \rightarrow [bD] \quad [bD] b \rightarrow b [Db]$$

~~$$D b \rightarrow b D$$~~

$$D c \rightarrow c D$$

$$D d \rightarrow d D$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e E$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$S \rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e$$

$$\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e$$

$$\rightarrow a a [Db] b [Ec] c d e$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$\begin{array}{lll} [cC] \rightarrow c[cC] & [Db] \rightarrow [bD] & [bD] b \rightarrow b [Db] \\ [cC] \rightarrow c & \cancel{D b \rightarrow b D} & [bD] c \rightarrow b [Dc] \\ & D c \rightarrow c D & E c \rightarrow c E \\ & D d \rightarrow d d & E d \rightarrow d E \\ & & E e \rightarrow e e \end{array}$$

$$\begin{array}{ll} [aAD] b \rightarrow [aA] [Db] & [bBE] c \rightarrow [bB] [Ec] \\ [aA] [Db] \rightarrow a [aAD] b & [bB] [Ec] \rightarrow b [bBE] c \\ \cancel{a [aAD] b \rightarrow a [aAD] b} & \cancel{b [bBE] c \rightarrow b [bBE] c} \\ \cancel{a [aAD] b \rightarrow a [aAD] b} & \cancel{b [bBE] c \rightarrow b [bBE] c} \\ \cancel{a [aAD] b \rightarrow a [aAD] b} & \cancel{b [bBE] c \rightarrow b [bBE] c} \end{array}$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$\begin{array}{l} S \rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e \\ \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e \\ \rightarrow a a [Db] b [Ec] c d e \end{array}$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$\begin{array}{lll} [cC] \rightarrow c[cC] & [Db] \rightarrow [bD] & [bD] b \rightarrow b [Db] \\ [cC] \rightarrow c & \cancel{D b \rightarrow b D} & [bD] c \rightarrow b [Dc] \\ & D c \rightarrow c D & [Dc] \rightarrow [cD] \\ & D d \rightarrow d d & E c \rightarrow c E \\ & & E d \rightarrow d E \\ & & E e \rightarrow e e \end{array}$$

$$\begin{array}{ll} [cC] \rightarrow c & [Db] \rightarrow [bD] \\ [cC] \rightarrow c & D c \rightarrow c D \\ & D d \rightarrow d d \end{array}$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$\begin{aligned} S \rightarrow & [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e \\ \rightarrow & a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e \\ \rightarrow & a a [Db] b [Ec] c d e \end{aligned}$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$[Db] \rightarrow [bD] \quad [bD] b \rightarrow b [Db]$$

~~$$D b \rightarrow b D$$~~

~~$$D c \rightarrow c D$$~~

$$D d \rightarrow d d$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$S \rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e$$

$$\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e$$

$$\rightarrow a a [Db] b [Ec] c d e$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \varepsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \varepsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$[cC] \rightarrow c [cC]$$

$$[Db] \rightarrow [bD] \quad [bD] b \rightarrow b [Db]$$

$$[cC] \rightarrow c$$

~~$$D b \rightarrow b D$$~~

$$[bD] c \rightarrow b [Dc]$$

$$E c \rightarrow c E$$

~~$$D c \rightarrow c D$$~~

$$[Dc] \rightarrow [cD]$$

$$E d \rightarrow d E$$

$$D d \rightarrow d d$$

$$[cD] c \rightarrow c [Dc]$$

$$E e \rightarrow e e$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$S \rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e$$

$$\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e$$

$$\rightarrow a a [Db] b [Ec] c d e$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$[cC] \rightarrow c[cC]$$

$$[cC] \rightarrow c$$

$$[Db] \rightarrow [bD] \quad [bD] b \rightarrow b [Db]$$

~~$$D b \rightarrow b D$$~~

~~$$D c \rightarrow c D$$~~

$$D d \rightarrow d d$$

$$[bD] c \rightarrow b [Dc]$$

$$[Dc] \rightarrow [cD]$$

$$[cD] c \rightarrow c [Dc]$$

$$[cD] d \rightarrow c d d$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$S \rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e$$

$$\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e$$

$$\rightarrow a a [Db] b [Ec] c d e$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

$$S \rightarrow [aA] [bB] [cC] d e \quad [aA] \rightarrow a [aAD] \quad [bB] \rightarrow b [bBE]$$

$$[aA] \rightarrow a \quad [bB] \rightarrow b$$

$$[cC] \rightarrow c[cC]$$

$$[cC] \rightarrow c$$

$$[Db] \rightarrow [bD] \quad [bD] b \rightarrow b [Db]$$

~~$$D b \rightarrow b D$$~~

~~$$D c \rightarrow c D$$~~

~~$$D d \rightarrow d D$$~~

$$[bD] c \rightarrow b [Dc]$$

$$[Dc] \rightarrow [cD]$$

$$[cD] c \rightarrow c [Dc]$$

$$[cD] d \rightarrow c d d$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e e$$

$$[aAD] b \rightarrow [aA] [Db] \quad [bBE] c \rightarrow [bB] [Ec]$$

$$S \rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e$$

$$\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e$$

$$\rightarrow a a [Db] b [Ec] c d e$$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

|   |  |  |
|---|--|--|
| $S \rightarrow [aA] [bB] [cC] d e$  | $[aA] \rightarrow a [aAD]$<br>$[aA] \rightarrow a$<br>$[Db] \rightarrow [bD]$<br>$[bD] b \rightarrow b [Db]$ | $[bB] \rightarrow b [bBE]$<br>$[bB] \rightarrow b$ |
| $[cC] \rightarrow c [cC]$   | $[bD] c \rightarrow b [Dc]$  | $E c \rightarrow c E$                              |
| $[cC] \rightarrow c$  | $[Dc] \rightarrow [cD]$  | $E d \rightarrow d E$                              |
|   | $[cD] c \rightarrow c [Dc]$  | $E e \rightarrow e e$                              |
|   | $[cD] d \rightarrow c d d$   |  |
| $[aAD] b \rightarrow [aA] [Db]$   | $[bBE] c \rightarrow [bB] [Ec]$  |  |
| $S \rightarrow [aA] [bB] [cC] d e \rightarrow a \underline{[aAD]} b \underline{[bBE]} c \underline{[cC]} d e$   |  |  |
| $\rightarrow a \underline{[aA]} \underline{[Db]} \underline{[bBE]} c \underline{[cC]} d e \rightarrow a \underline{[aA]} [Db] \underline{[bB]} \underline{[Ec]} \underline{[cC]} d e$ |  |  |
| $\rightarrow a a [Db] b [Ec] c d e$   |  |  |

## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

$S \rightarrow [aA] [bB] [cC] d e$        $[aA] \rightarrow a [aAD]$        $[bB] \rightarrow b [bBE]$   
                                         $[aA] \rightarrow a$                                    $[bB] \rightarrow b$   
  
 $[Db] \rightarrow [bD]$        $[Ec] \rightarrow [cE]$   
 $[bD] b \rightarrow b [Db]$        $[cE] c \rightarrow c [Ec]$   
 $[cC] \rightarrow c [cC]$        $[bD] c \rightarrow b [Dc]$        $[cE] d \rightarrow c [Ed]$        $E c \rightarrow c E$   
 $[cC] \rightarrow c$        $[Dc] \rightarrow [cD]$        $[Ed] \rightarrow [dE]$        $E d \rightarrow d E$   
 $[cD] c \rightarrow c [Dc]$        $[dE] d \rightarrow d [Ed]$        $E e \rightarrow e e$   
 $[cD] d \rightarrow c d d$        $[dE] e \rightarrow d e e$   
  
 $[aAD] b \rightarrow [aA] [Db]$        $[bBE] c \rightarrow [bB] [Ec]$   
  
 $S \rightarrow [aA] [bB] [cC] d e \rightarrow a [aAD] b [bBE] c [cC] d e$   
 $\rightarrow a [aA] [Db] [bBE] c [cC] d e \rightarrow a [aA] [Db] [bB] [Ec] [cC] d e$   
 $\rightarrow a a [Db] b [Ec] c d e$



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

|   |  |  |
|---|--|--|
| $S \rightarrow [aA] [bB] [cC] d e$  | $[aA] \rightarrow a [aAD]$<br>$[aA] \rightarrow a$ | $[bB] \rightarrow b [bBE]$<br>$[bB] \rightarrow b$ |
|   | $[Db] \rightarrow [bD]$                            | $[Ec] \rightarrow [cE]$                            |
|   | $[bD] b \rightarrow b [Db]$                        | $[cE] c \rightarrow c [Ec]$                        |
| $[cC] \rightarrow c [cC]$   | $[bD] c \rightarrow b [Dc]$                        | $[cE] d \rightarrow c [Ed]$                        |
| $[cC] \rightarrow c$  | $[Dc] \rightarrow [cD]$                            | $[Ed] \rightarrow [dE]$                            |
|   | $[cD] c \rightarrow c [Dc]$                        | $[dE] d \rightarrow d [Ed]$                        |
|   | $[cD] d \rightarrow c d d$                         |  |
| $[aAD] b \rightarrow [aA] [Db]$   | $[bBE] c \rightarrow [bB] [Ec]$                    | $[dE] e \rightarrow d e e$                         |
| $S \rightarrow [aA] [bB] [cC] d e \rightarrow a [aAD] b [bBE] c [cC] d e$             |  |  |
| $\rightarrow a [aA] [Db] [bBE] c [cC] d e \rightarrow a [aA] [Db] [bB] [Ec] [cC] d e$ |  |  |
| $\rightarrow a a [Db] b [Ec] c d e$   |  |  |



## Task 32

Productions of *context-sensitive grammar*:

- $\alpha \rightarrow \beta$ ,  $|\beta| \geq |\alpha|$ ,  $\alpha \neq \epsilon$
- $\alpha_1 A \alpha_2 \rightarrow \alpha_1 \beta \alpha_2$ ,  $\beta \neq \epsilon$

|   |  |  |
|---|--|--|
| $S \rightarrow [aA] [bB] [cC] d e$  | $[aA] \rightarrow a [aAD]$<br>$[aA] \rightarrow a$ | $[bB] \rightarrow b [bBE]$<br>$[bB] \rightarrow b$ |
|   | $[Db] \rightarrow [bD]$                            | $[Ec] \rightarrow [cE]$                            |
|   | $[bD] b \rightarrow b [Db]$                        | $[cE] c \rightarrow c [Ec]$                        |
| $[cC] \rightarrow c [cC]$   | $[bD] c \rightarrow b [Dc]$                        | $[cE] d \rightarrow c [Ed]$                        |
| $[cC] \rightarrow c$  | $[Dc] \rightarrow [cD]$                            | $[Ed] \rightarrow [dE]$                            |
|   | $[cD] c \rightarrow c [Dc]$                        | $[dE] d \rightarrow d [Ed]$                        |
|   | $[cD] d \rightarrow c d d$                         |  |
| $[aAD] b \rightarrow [aA] [Db]$   | $[bBE] c \rightarrow [bB] [Ec]$                    | $[dE] e \rightarrow d e e$                         |
| $S \rightarrow [aA] [bB] [cC] d e \rightarrow a [aAD] b [bBE] c [cC] d e$             |  |  |
| $\rightarrow a [aA] [Db] [bBE] c [cC] d e \rightarrow a [aA] [Db] [bB] [Ec] [cC] d e$ |  |  |
| $\rightarrow a a [Db] b [Ec] c d e \rightarrow a a b b c c d d e e$                   |  |  |



## Task 32

Solution:

$$S \rightarrow [aA] [bB] [cC] d e$$

$$[aA] \rightarrow a [aAD]$$

$$[aA] \rightarrow a$$

$$[aAD] b \rightarrow [aA] [Db]$$

$$[bB] \rightarrow b [bBE]$$

$$[bB] \rightarrow b$$

$$[bBE] c \rightarrow [bB] [Ec]$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$[Db] \rightarrow [bD]$$

$$[bD] b \rightarrow b [Db]$$

$$[bD] c \rightarrow b [Dc]$$

$$[Dc] \rightarrow [cD]$$

$$[cD] c \rightarrow c [Dc]$$

$$[cD] d \rightarrow c d d$$

$$[Ec] \rightarrow [cE]$$

$$[cE] c \rightarrow c [Ec]$$

$$[cE] d \rightarrow c [Ed]$$

$$[Ed] \rightarrow [dE]$$

$$[dE] d \rightarrow d [Ed]$$

$$[dE] e \rightarrow d e e$$



## Task 32

Solution:

Shorter solution: the method is conducted only for empty nonterminal symbols

$$S \rightarrow [aA] [bB] [cC] d e$$

$$[aA] \rightarrow a [aAD]$$

$$[aA] \rightarrow a$$

$$[aAD] b \rightarrow [aA] [Db]$$

$$[bB] \rightarrow b [bBE]$$

$$[bB] \rightarrow b$$

$$[bBE] c \rightarrow [bB] [Ec]$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$[Db] \rightarrow [bD]$$

$$[bD] b \rightarrow b [Db]$$

$$[bD] c \rightarrow b [Dc]$$

$$[Dc] \rightarrow [cD]$$

$$[cD] c \rightarrow c [Dc]$$

$$[cD] d \rightarrow c d d$$

$$[Ec] \rightarrow [cE]$$

$$[cE] c \rightarrow c [Ec]$$

$$[cE] d \rightarrow c [Ed]$$

$$[Ed] \rightarrow [dE]$$

$$[dE] d \rightarrow d [Ed]$$

$$[dE] e \rightarrow d e e$$



## Task 32

Solution:

Shorter solution: the method is conducted only for empty nonterminal symbols

$$S \rightarrow [aA] [bB] [cC] d e$$

$$[aA] \rightarrow a [aAD]$$

$$[aA] \rightarrow a$$

$$[aAD] b \rightarrow [aA] [Db]$$

$$[bB] \rightarrow b [bBE]$$

$$[bB] \rightarrow b$$

$$[bBE] c \rightarrow [bB] [Ec]$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

~~$$[Db] \rightarrow [bD]$$~~

~~$$[bD] b \rightarrow b [Db]$$~~

~~$$[bD] c \rightarrow b [Dc]$$~~

~~$$[Dc] \rightarrow [cD]$$~~

~~$$[cD] c \rightarrow c [Ds]$$~~

~~$$[cD] d \rightarrow c d d$$~~

$$[Ec] \rightarrow [cE]$$

$$[cE] c \rightarrow c [Ec]$$

$$[cE] d \rightarrow c [Ed]$$

$$[Ed] \rightarrow [dE]$$

$$[dE] d \rightarrow d [Ed]$$

$$[dE] e \rightarrow d e e$$



## Task 32

Solution:

Shorter solution: the method is conducted only for empty nonterminal symbols

$$S \rightarrow [aA] [bB] [cC] d e$$

$$[aA] \rightarrow a [aAD]$$

$$[aA] \rightarrow a$$

$$[aAD] b \rightarrow [aA] [Db]$$

$$[bB] \rightarrow b [bBE]$$

$$[bB] \rightarrow b$$

$$[bBE] c \rightarrow [bB] [Ec]$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

~~$$[Db] \rightarrow [bD]$$~~

~~$$[bD] b \rightarrow b [Db]$$~~

~~$$[bD] c \rightarrow b [Dc]$$~~

~~$$[Dc] \rightarrow [cD]$$~~

~~$$[cD] c \rightarrow c [Ds]$$~~

~~$$[cD] d \rightarrow c d d$$~~

~~$$[Ec] \rightarrow [cE]$$~~

~~$$[cE] c \rightarrow c [Ec]$$~~

~~$$[cE] d \rightarrow c [Ed]$$~~

~~$$[Ed] \rightarrow [dE]$$~~

~~$$[dE] d \rightarrow d [Ed]$$~~

~~$$[dE] e \rightarrow d e e$$~~

## Task 32

Solution:

Shorter solution: the method is conducted only for empty nonterminal symbols

$$S \rightarrow [aA] [bB] [cC] d e$$

$$[aA] \rightarrow a [aAD]$$

$$[aA] \rightarrow a$$

$$[aAD] b \rightarrow [aA] [Db]$$

$$[bB] \rightarrow b [bBE]$$

$$[bB] \rightarrow b$$

$$[bBE] c \rightarrow [bB] [Ec]$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d D$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e E$$



## Task 32

Solution:

Shorter solution: the method is conducted only for empty nonterminal symbols

$$S \rightarrow [aA] [bB] [cC] d e$$

~~$$[aA] \rightarrow a [aAD]$$~~

$$[aA] \rightarrow a \quad [aA] \rightarrow a [aA] D$$

~~$$[aAD] b \rightarrow [aA] [Db]$$~~

$$[bB] \rightarrow b [bBE]$$

$$[bB] \rightarrow b$$

$$[bBE] c \rightarrow [bB] [Ec]$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d D$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e E$$

## Task 32

Solution:

Shorter solution: the method is conducted only for empty nonterminal symbols

$$S \rightarrow [aA] [bB] [cC] d e$$

~~$$[aA] \rightarrow a [aAD]$$~~

$$[aA] \rightarrow a \quad [aA] \rightarrow a [aA] D$$

~~$$[aAD] b \rightarrow [aA] [Db]$$~~

$$[bB] \rightarrow b [bB] E$$

~~$$[bB] \rightarrow b [bBE]$$~~

$$[bB] \rightarrow b$$

~~$$[bBE] c \rightarrow [bB] [Ec]$$~~

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d D$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e E$$

## Task 32

Solution:

Shorter solution: the method is conducted only for empty nonterminal symbols

$$S \rightarrow [aA] [bB] [cC] d e$$

$$[aA] \rightarrow a [aA] D$$

$$[aA] \rightarrow a$$

~~$$[aAD] b \rightarrow [aA] [Db]$$~~

$$[bB] \rightarrow b [bB] E$$

~~$$[bB] \rightarrow b [bBE]$$~~

$$[bB] \rightarrow b$$

~~$$[bBE] c \rightarrow [bB] [Ec]$$~~

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d D$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e E$$

## Task 32

Solution:

Shorter solution: the method is conducted only for empty nonterminal symbols

$$S \rightarrow [aA] [bB] [cC] d e$$

$$[aA] \rightarrow a [aA] D$$

$$[aA] \rightarrow a$$

$$[bB] \rightarrow b [bB] E$$

$$[bB] \rightarrow b$$

$$[cC] \rightarrow c [cC]$$

$$[cC] \rightarrow c$$

$$D b \rightarrow b D$$

$$D c \rightarrow c D$$

$$D d \rightarrow d D$$

$$E c \rightarrow c E$$

$$E d \rightarrow d E$$

$$E e \rightarrow e E$$

## Task 33

- Construct grammar that generates sequences in the following form:  $0^n 1^n 2^n$  where  $n \geq 0$ .

$$L = \{0^n 1^n 2^n \mid n \geq 0\}$$

## Task 33

$$L = \{0^n 1^n 2^n \mid n \geq 0\}$$

## Task 33

$$L = \{0^n 1^n 2^n \mid n \geq 0\}$$

$$S \rightarrow 0A12$$

$$S \rightarrow \epsilon$$

$$A \rightarrow 0AB$$

$$A \rightarrow \epsilon$$

$$B1 \rightarrow 11C$$

$$C1 \rightarrow 1C$$

$$C2 \rightarrow 22$$

## Task 33

$$L = \{0^n 1^n 2^n \mid n \geq 0\}$$

$$S \rightarrow 0A12$$

$$S \rightarrow \epsilon$$

$$A \rightarrow 0AB$$

$$A \rightarrow \epsilon$$

$$B1 \rightarrow 11C$$

$$C1 \rightarrow 1C$$

$$C2 \rightarrow 22$$

- $n = 0$  (trivial case)

$$S \rightarrow \epsilon$$

unrestricted grammar

## Task 33

$$L = \{0^n 1^n 2^n \mid n \geq 0\}$$

$$S \rightarrow 0A12$$

$$S \rightarrow \epsilon$$

$$A \rightarrow 0AB$$

$$A \rightarrow \epsilon$$

$$B1 \rightarrow 11C$$

$$C1 \rightarrow 1C$$

$$C2 \rightarrow 22$$

- $n = 0$  (trivial case)

$$S \rightarrow \epsilon$$

unrestricted grammar

- $n = 1$

S

## Task 33

$$L = \{0^n 1^n 2^n \mid n \geq 0\}$$

$$S \rightarrow 0A12$$

$$S \rightarrow \epsilon$$

$$A \rightarrow 0AB$$

$$A \rightarrow \epsilon$$

$$B1 \rightarrow 11C$$

$$C1 \rightarrow 1C$$

$$C2 \rightarrow 22$$

- $n = 0$  (trivial case)

$$S \rightarrow \epsilon$$

unrestricted grammar

- $n = 1$

S

0 A 1 2

## Task 33

$$L = \{0^n 1^n 2^n \mid n \geq 0\}$$

$$S \rightarrow 0A12$$

$$S \rightarrow \epsilon$$

$$A \rightarrow 0AB$$

$$A \rightarrow \epsilon$$

$$B1 \rightarrow 11C$$

$$C1 \rightarrow 1C$$

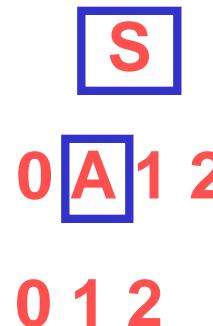
$$C2 \rightarrow 22$$

- $n = 0$  (trivial case)

$$S \rightarrow \epsilon$$

unrestricted grammar

- $n = 1$



## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$S$

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

S

0 A 1 2

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$\begin{array}{c} S \\ | \\ 0 A 1 2 \\ | \\ 0 0 A B 1 2 \end{array}$

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

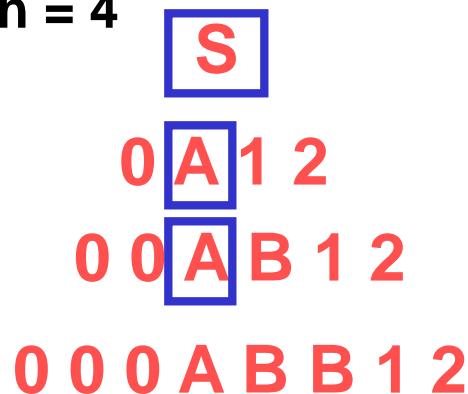
4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$



## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$\begin{array}{c} S \\ | \\ 0 A 1 2 \\ | \\ 0 0 A B 1 2 \\ | \\ 0 0 0 A B B 1 2 \\ | \\ 0 0 0 0 A B B B 1 2 \end{array}$

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$\begin{array}{c} S \\ | \\ 0 A 1 2 \\ | \\ 0 0 A B 1 2 \\ | \\ 0 0 0 A B B 1 2 \\ | \\ 0 0 0 0 A B B B 1 2 \\ | \\ 0 0 0 0 B B B 1 2 \end{array}$

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$S$   
0  $A$  1 2  
0 0  $A$  B 1 2  
0 0 0  $A$  B B 1 2  
0 0 0 0  $A$  B B B 1 2  
0 0 0 0 B B  $B$  1 2  
0 0 0 0 B B 1 1 C 2

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$S$   
0 A 1 2  
0 0 A B 1 2  
0 0 0 A B B 1 2  
0 0 0 0 A B B B 1 2  
0 0 0 0 B B B 1 2  
0 0 0 0 B B 1 1 C 2  
0 0 0 0 B 1 1 C 1 C 2

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$S$   
0  $A$  1 2  
0 0  $A$  B 1 2  
0 0 0  $A$  B B 1 2  
0 0 0 0  $A$  B B B 1 2  
0 0 0 0 B B  $B$  1 2  
0 0 0 0 B  $B$  1 1 C 2  
0 0 0 0 B 1 1 C 1 C 2  
0 0 0 0 1 1 C 1 C 1 C 2

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

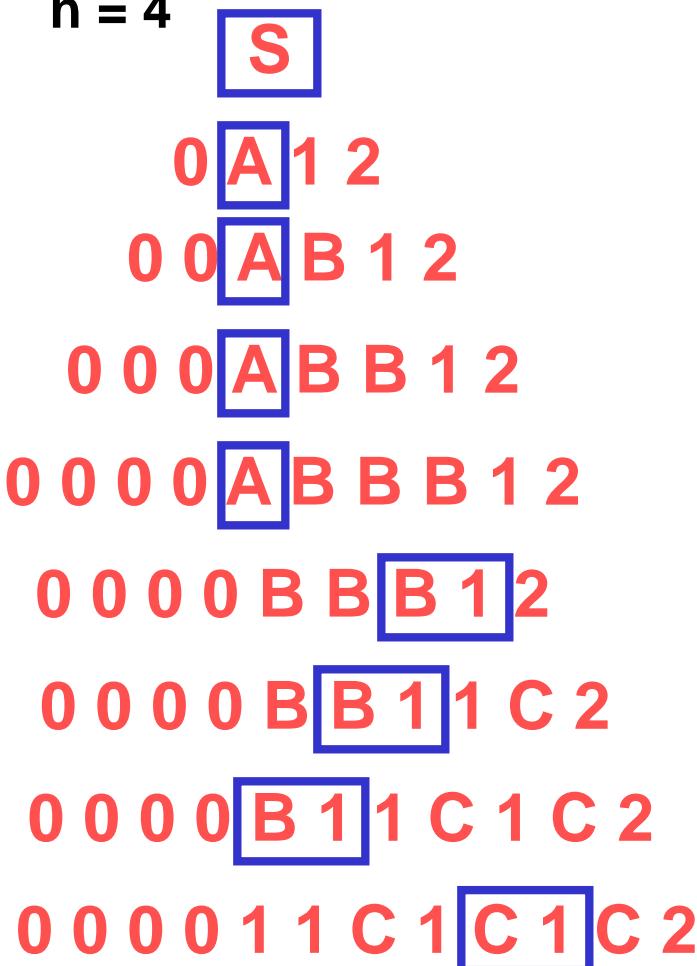
4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$



$000011C11CC2$

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$S$   
0 A 1 2  
0 0 A B 1 2  
0 0 0 A B B 1 2  
0 0 0 0 A B B B 1 2  
0 0 0 0 B B B 1 2  
0 0 0 0 B B 1 1 C 2  
0 0 0 0 B 1 1 C 1 C 2  
0 0 0 0 1 1 C 1 C 1 C 2

0 0 0 0 1 1 C 1 1 C C 2  
0 0 0 0 1 1 1 C 1 C C 2

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$S$   
 $0A12$   
 $00AB12$   
 $000ABBB12$   
 $0000ABB12$   
 $0000B(B12$   
 $0000B(B11C2$   
 $0000B(B11C1C2$   
 $000011C1(C1C2$

$000011C11CC2$   
 $0000111C1CC2$   
 $00001111CCC2$

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$S$   
 $0A12$   
 $00AB12$   
 $000ABBB12$   
 $0000ABB12$   
 $0000B(B12$   
 $0000B(B11C2$   
 $0000B(B11C1C2$   
 $000011C1(C1C2$

$000011C11CC2$   
 $0000111C1CC2$   
 $00001111CC2$   
 $00001111CC22$

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$

$S$   
 $0A12$   
 $00AB12$   
 $000ABBB12$   
 $0000ABB12$   
 $0000B(B1)2$   
 $0000B(B11)C2$   
 $0000(B11)C1C2$   
 $000011C1(C1)C2$

$000011C11CC2$   
 $0000111C1CC2$   
 $00001111CCC2$   
 $00001111CC22$   
 $00001111C222$

## Task 33

1)  $S \rightarrow 0A12$

2)  $S \rightarrow \epsilon$

3)  $A \rightarrow 0AB$

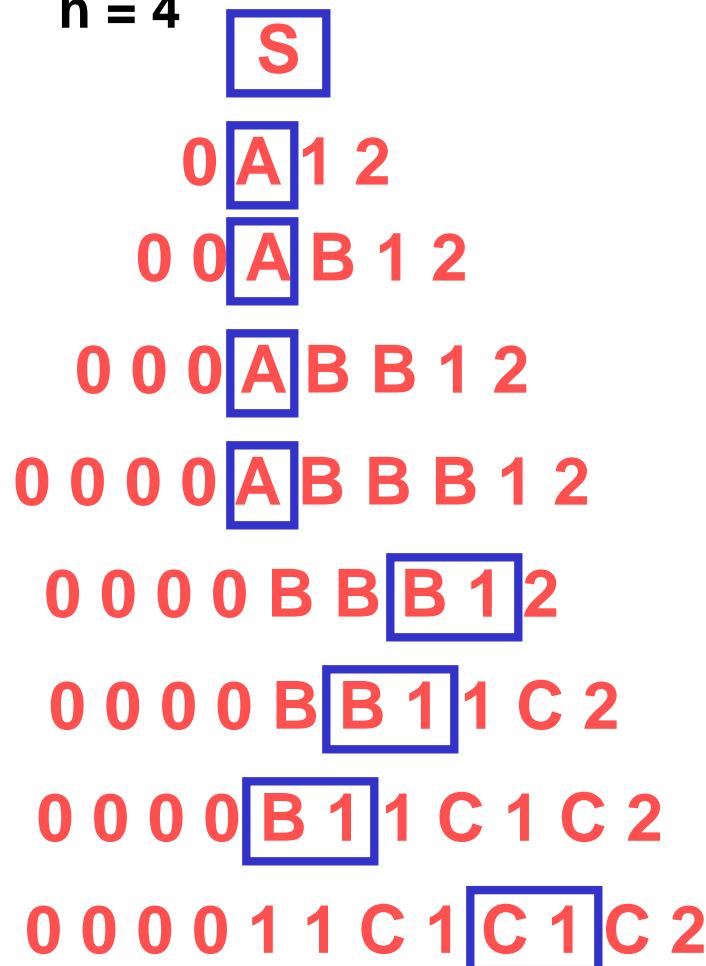
4)  $A \rightarrow \epsilon$

5)  $B1 \rightarrow 11C$

6)  $C1 \rightarrow 1C$

7)  $C2 \rightarrow 22$

- $n = 4$



000011C11CC2  
0000111C1CC2  
00001111CCC2  
00001111CC22  
00001111C222  
000011112222

## Task 34

Construct context-sensitive grammar that generates sequences from language L.

## Task 34

Construct context-sensitive grammar that generates sequences from language L.

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$S$

## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

S

A X

## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

S

AX

0 A B X

## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$\boxed{S}$

$\boxed{A}X$

$0\boxed{A}B X$

$0 0 A B B X$

## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$\boxed{S}$

$\boxed{A}X$

$0\boxed{A}B X$

$0\ 0\ \boxed{A}B\ B\ X$

$0\ 0\ 0\ \boxed{A}B\ B\ B\ X$

$0\ 0\ 0\ 0\ B\ B\ B\ B\ X$

## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

$0 0 0 0 B B B B X$

$0 0 0 0 B B B 1 2$

## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

$0 0 0 0 B B B B X$

$0 0 0 0 B B B 1 2$

$0 0 0 0 B B 1 B 2$

## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$\boxed{S}$

0 0 0 0 B 1 B B 2

$\boxed{A} X$

0  $\boxed{A} B X$

0 0  $\boxed{A} B B X$

0 0 0  $\boxed{A} B B B X$

0 0 0 0 B B B  $\boxed{B} X$

0 0 0 0 B B  $\boxed{B} 1 2$

0 0 0 0 B  $\boxed{B} 1 B 2$



## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

$0 0 0 0 B B B B X$

$0 0 0 0 B B B 1 2$

$0 0 0 0 B B 1 B 2$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$0 0 0 0 B 1 B 2$

$0 0 0 0 1 B B B 2$



## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

$0 0 0 0 B B B B X$

$0 0 0 0 B B B 1 2$

$0 0 0 0 B B 1 B 2$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$0 0 0 0 B 1 B 2$

$0 0 0 0 1 B B B 2$

$0 0 0 0 1 B B 1 2 2$



## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

$0 0 0 0 B B B B X$

$0 0 0 0 B B B 1 2$

$0 0 0 0 B B 1 B 2$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$0 0 0 0 B 1 B 2$

$0 0 0 0 1 B B B 2$

$0 0 0 0 1 B B 1 2 2$

$0 0 0 0 1 B 1 B 2 2$



## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

$0 0 0 0 B B B B X$

$0 0 0 0 B B B 1 2$

$0 0 0 0 B B 1 B 2$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$0 0 0 0 B 1 B 2$

$0 0 0 0 1 B B 2$

$0 0 0 0 1 B B 1 2 2$

$0 0 0 0 1 B 1 B 2 2$

$0 0 0 0 1 1 B B 2 2$



## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

$0 0 0 0 B B B B X$

$0 0 0 0 B B B 1 2$

$0 0 0 0 B B 1 B 2$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$0 0 0 0 B 1 B 2$

$0 0 0 0 1 B B 2$

$0 0 0 0 1 B B 1 2 2$

$0 0 0 0 1 B 1 B 2 2$

$0 0 0 0 1 1 B B 2 2$

$0 0 0 0 1 1 B 1 2 2 2$



## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

$0 0 0 0 B B B B X$

$0 0 0 0 B B B 1 2$

$0 0 0 0 B B 1 B 2$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$0 0 0 0 B 1 B 2$

$0 0 0 0 1 B B 2$

$0 0 0 0 1 B B 1 2 2$

$0 0 0 0 1 B 1 B 2 2$

$0 0 0 0 1 1 B B 2 2$

$0 0 0 0 1 1 B 1 2 2 2$

$0 0 0 0 1 1 1 B 2 2 2$



## Task 34

$$L = \{0^n 1^n 2^n \mid n \geq 1\}$$

$S \rightarrow AX$

$A \rightarrow 0AB$

$A \rightarrow 0B$

$S$

$AX$

$0A B X$

$0 0 A B B X$

$0 0 0 A B B B X$

$0 0 0 0 B B B B X$

$0 0 0 0 B B B 1 2$

$0 0 0 0 B B 1 B 2$

$BX \rightarrow 12$

$B1 \rightarrow 1B$

$B2 \rightarrow 122$

$0 0 0 0 B 1 B 2$

$0 0 0 0 1 B B 2$

$0 0 0 0 1 B B 1 2 2$

$0 0 0 0 1 B 1 B 2 2$

$0 0 0 0 1 1 B B 2 2$

$0 0 0 0 1 1 B 1 2 2 2$

$0 0 0 0 1 1 1 B 2 2 2$

$0 0 0 0 1 1 1 1 2 2 2 2$



# Task 35

## Task 35

Construct grammar that generates sequences from a language that accepts TM M.

## Task 35

Construct grammar that generates sequences from a language that accepts TM M.

**TM M=**(  
    {q0,q1,q2,q3,q4,q5,qP},  
    {0,1},  
    {0,1,B},  
    δ,  
    q0,  
    B,  
    qP  
)

## Task 35

Construct grammar that generates sequences from a language that accepts TM M.

TM M=(

{q0,q1,q2,q3,q4,q5,qP},

{0,1},

{0,1,B},

$\delta$ ,

q0,

B,

qP

)

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |



## Initial configuration:

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

## Initial configuration:

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

## Adding empty cells:

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\epsilon, B] A_3$
- 5)  $A_3 \rightarrow \epsilon$

### Initial configuration:

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

### Adding empty cells:

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

Transition TS M :

$$\delta( q, X ) = ( p, Y, R )$$

**Initial configuration:**

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

**Adding empty cells:**

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

**Transition TS M :**

$$\delta(q, X) = (p, Y, R)$$

**Grammar productions:**

- 6)  $q [ a, X ] \rightarrow [ a, Y ] p$



**Initial configuration:**

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

**Adding empty cells:**

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\epsilon, B] A_3$
- 5)  $A_3 \rightarrow \epsilon$

**Transition TS M :**

$$\delta(q, X) = (p, Y, R)$$

**Grammar productions:**

- 6)  $q [ a, X ] \rightarrow [ a, Y ] p$

**Transition TM M :**

$$\delta(q, X) = (p, Y, L)$$

**Initial configuration:**

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

**Adding empty cells:**

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\epsilon, B] A_3$
- 5)  $A_3 \rightarrow \epsilon$

**Transition TS M :**

$$\delta(q, X) = (p, Y, R)$$

**Grammar productions:**

- 6)  $q [ a, X ] \rightarrow [ a, Y ] p$

**Transition TM M :**

$$\delta(q, X) = (p, Y, L)$$

**Grammar productions:**

- 7)  $[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$

**Initial configuration:**

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

**Adding empty cells:**

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\epsilon, B] A_3$
- 5)  $A_3 \rightarrow \epsilon$

**Transition TS M :**

$$\delta(q, X) = (p, Y, R)$$

**Grammar productions:**

- 6)  $q [ a, X ] \rightarrow [ a, Y ] p$

**Transition TM M :**

$$\delta(q, X) = (p, Y, L)$$

**Grammar productions:**

- 7)  $[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$

**For all states  $q \in F$**



**Initial configuration:**

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

**Adding empty cells:**

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

**Transition TS M :**

$$\delta(q, X) = (p, Y, R)$$

**Grammar productions:**

- 6)  $q [ a, X ] \rightarrow [ a, Y ] p$

**Transition TM M :**

$$\delta(q, X) = (p, Y, L)$$

**Grammar productions:**

- 7)  $[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$

**For all states  $q \in F$**

**For all symbols  $a \in \Sigma \cup \{ \varepsilon \}$**



**Initial configuration:**

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

**Adding empty cells:**

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

**Transition TS M :**

$$\delta(q, X) = (p, Y, R)$$

**Grammar productions:**

- 6)  $q [ a, X ] \rightarrow [ a, Y ] p$

**Transition TM M :**

$$\delta(q, X) = (p, Y, L)$$

**Grammar productions:**

- 7)  $[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$

**For all states  $q \in F$**

**For all symbols  $a \in \Sigma \cup \{ \varepsilon \}$**

**For all symbols  $X \in \Gamma$**



**Initial configuration:**

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

**Adding empty cells:**

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

**Transition TS M :**

$$\delta(q, X) = (p, Y, R)$$

**Grammar productions:**

- 6)  $q [ a, X ] \rightarrow [ a, Y ] p$

**Transition TM M :**

$$\delta(q, X) = (p, Y, L)$$

**Grammar productions:**

- 7)  $[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$

**For all states  $q \in F$**

**For all symbols  $a \in \Sigma \cup \{ \varepsilon \}$**

**For all symbols  $X \in \Gamma$**

- 8)  $[a, X] q \rightarrow q a q$
- 9)  $q [a, X] \rightarrow q a q$
- 10)  $q \rightarrow \varepsilon$



|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

## Initial productions:

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

## Initial productions:

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

## Initial configuration:

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

## Adding empty cells:

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

**Initial productions:**

$$A_1 \rightarrow q_0 A_2$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

**Initial configuration:**

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

**Adding empty cells:**

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

## Initial configuration:

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

## Adding empty cells:

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

## Initial configuration:

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

## Adding empty cells:

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

$$A_2 \rightarrow A_3$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

## Initial configuration:

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

## Adding empty cells:

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

$$A_2 \rightarrow A_3$$

$$A_3 \rightarrow [\varepsilon, B] A_3$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

## Initial configuration:

- 1)  $A_1 \rightarrow q_0 A_2$
- 2)  $A_2 \rightarrow [a, a] A_2$

## Adding empty cells:

- 3)  $A_2 \rightarrow A_3$
- 4)  $A_3 \rightarrow [\varepsilon, B] A_3$
- 5)  $A_3 \rightarrow \varepsilon$

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

$$A_2 \rightarrow A_3$$

$$A_3 \rightarrow [\varepsilon, B] A_3$$

$$A_3 \rightarrow \varepsilon$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

## Initial configuration:

$$1) \quad A_1 \rightarrow q_0 A_2$$

$$2) \quad A_2 \rightarrow [a, a] A_2$$

## Adding empty cells:

$$3) \quad A_2 \rightarrow A_3$$

$$4) \quad A_3 \rightarrow [\varepsilon, B] A_3$$

$$5) \quad A_3 \rightarrow \varepsilon$$

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

$$A_2 \rightarrow A_3$$

$$A_3 \rightarrow [\varepsilon, B] A_3$$

$$A_3 \rightarrow \varepsilon$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

$$A_2 \rightarrow A_3$$

$$A_3 \rightarrow [\varepsilon, B] A_3$$

$$A_3 \rightarrow \varepsilon$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

For transition  $\delta(q_0, 0) = (q_1, B, R)$ :

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

$$A_2 \rightarrow A_3$$

$$A_3 \rightarrow [\varepsilon, B] A_3$$

$$A_3 \rightarrow \varepsilon$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

For transition  $\delta(q_0, 0) = (q_1, B, R)$ :

$$\delta(q, X) = (p, Y, R)$$

6)  $q [ a, X ] \rightarrow [ a, Y ] p$

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

$$A_2 \rightarrow A_3$$

$$A_3 \rightarrow [\varepsilon, B] A_3$$

$$A_3 \rightarrow \varepsilon$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

For transition  $\delta(q_0, 0) = (q_1, B, R)$ :

$$q_0 [0,0] \rightarrow [0,B] q_1$$

$$q_0 [1,0] \rightarrow [1,B] q_1$$

$$q_0 [\varepsilon,0] \rightarrow [\varepsilon,B] q_1$$

$$\delta( q, X ) = ( p, Y, R )$$

$$6) \quad q [ a, X ] \rightarrow [ a, Y ] p$$

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

$$A_2 \rightarrow A_3$$

$$A_3 \rightarrow [\varepsilon, B] A_3$$

$$A_3 \rightarrow \varepsilon$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

For transition  $\delta(q_0, 0) = (q_1, B, R)$ :

$$q_0 [0,0] \rightarrow [0,B] q_1$$

$$q_0 [1,0] \rightarrow [1,B] q_1$$

$$q_0 [\varepsilon, 0] \rightarrow [\varepsilon,B] q_1$$

## Initial productions:

$$A_1 \rightarrow q_0 A_2$$

$$A_2 \rightarrow [0,0] A_2$$

$$A_2 \rightarrow [1,1] A_2$$

$$A_2 \rightarrow A_3$$

$$A_3 \rightarrow [\varepsilon, B] A_3$$

$$A_3 \rightarrow \varepsilon$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

For transition  $\delta(q_0, 0) = (q_1, B, R)$ :

$$q_0 [0,0] \rightarrow [0,B] q_1$$

$$q_0 [1,0] \rightarrow [1,B] q_1$$

$$q_0 [\varepsilon, 0] \rightarrow [\varepsilon,B] q_1$$

For transition:  $\delta(q_0, 1) = (q_2, B, R)$ :

$$q_0 [0,1] \rightarrow [0,B] q_2$$

$$q_0 [1,1] \rightarrow [1,B] q_2$$

$$q_0 [\varepsilon, 1] \rightarrow [\varepsilon,B] q_2$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

6)  $q [ a, X ] \rightarrow [ a, Y ] p$

For transition  $\delta(q_0, B) = (q_P, B, R)$ :

$$q_0[0, B] \rightarrow [0, B] q_P$$

$$q_0[1, B] \rightarrow [1, B] q_P$$

$$q_0[\varepsilon, B] \rightarrow [\varepsilon, B] q_P$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_P, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$6) \quad q [ a, X ] \rightarrow [ a, Y ] p$$



For transition  $\delta(q_0, B) = (q_P, B, R)$ :

$$q_0[0, B] \rightarrow [0, B] q_P$$

$$q_0[1, B] \rightarrow [1, B] q_P$$

$$q_0[\varepsilon, B] \rightarrow [\varepsilon, B] q_P$$

For transition  $\delta(q_1, 0) = (q_1, 0, R)$ :

$$q_1[0, 0] \rightarrow [0, 0] q_1$$

$$q_1[1, 0] \rightarrow [1, 0] q_1$$

$$q_1[\varepsilon, 0] \rightarrow [\varepsilon, 0] q_1$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_P, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

6)  $q[a, X] \rightarrow [a, Y] p$

For transition  $\delta(q_0, B) = (q_P, B, R)$ :

$$q_0[0, B] \rightarrow [0, B] q_P$$

$$q_0[1, B] \rightarrow [1, B] q_P$$

$$q_0[\varepsilon, B] \rightarrow [\varepsilon, B] q_P$$

For transition  $\delta(q_1, 0) = (q_1, 0, R)$ :

$$q_1[0, 0] \rightarrow [0, 0] q_1$$

$$q_1[1, 0] \rightarrow [1, 0] q_1$$

$$q_1[\varepsilon, 0] \rightarrow [\varepsilon, 0] q_1$$

For transition  $\delta(q_1, 1) = (q_1, 1, R)$ :

$$q_1[0, 1] \rightarrow [0, 1] q_1$$

$$q_1[1, 1] \rightarrow [1, 1] q_1$$

$$q_1[\varepsilon, 1] \rightarrow [\varepsilon, 1] q_1$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_P, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

6)  $q[a, X] \rightarrow [a, Y] p$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

For transition  $\delta(q_1, B) = (q_3, B, L)$ :

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

For transition  $\delta(q_1, B) = (q_3, B, L)$ :

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$\delta(q, X) = (p, Y, L)$$

$$7) [b, Z] q [a, X] \rightarrow p [b, Z] [a, Y]$$

For transition  $\delta(q_1, B) = (q_3, B, L)$ :

[0,0]  $q_1 [0,B] \rightarrow q_3 [0,0] [0,B]$

[0,0]  $q_1 [1,B] \rightarrow q_3 [0,0] [1,B]$

[0,0]  $q_1 [\varepsilon,B] \rightarrow q_3 [0,0] [\varepsilon,B]$

[0,1]  $q_1 [0,B] \rightarrow q_3 [0,1] [0,B]$

[0,1]  $q_1 [1,B] \rightarrow q_3 [0,1] [1,B]$

[0,1]  $q_1 [\varepsilon,B] \rightarrow q_3 [0,1] [\varepsilon,B]$

[0,B]  $q_1 [0,B] \rightarrow q_3 [0,B] [0,B]$

[0,B]  $q_1 [1,B] \rightarrow q_3 [0,B] [1,B]$

[0,B]  $q_1 [\varepsilon,B] \rightarrow q_3 [0,B] [\varepsilon,B]$

[1,0]  $q_1 [0,B] \rightarrow q_3 [1,0] [0,B]$

[1,0]  $q_1 [1,B] \rightarrow q_3 [1,0] [1,B]$

[1,0]  $q_1 [\varepsilon,B] \rightarrow q_3 [1,0] [\varepsilon,B]$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

[1,1]  $q_1 [0,B] \rightarrow q_3 [1,1] [0,B]$

[1,1]  $q_1 [1,B] \rightarrow q_3 [1,1] [1,B]$

[1,1]  $q_1 [\varepsilon,B] \rightarrow q_3 [1,1] [\varepsilon,B]$

[1,B]  $q_1 [0,B] \rightarrow q_3 [1,B] [0,B]$

[1,B]  $q_1 [1,B] \rightarrow q_3 [1,B] [1,B]$

$\delta( q, X ) = ( p, Y, L )$

7)  $[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$

For transition  $\delta(q_1, B) = (q_3, B, L)$ :

[0,0]  $q_1 [0,B] \rightarrow q_3 [0,0] [0,B]$

[0,0]  $q_1 [1,B] \rightarrow q_3 [0,0] [1,B]$

[0,0]  $q_1 [\varepsilon,B] \rightarrow q_3 [0,0] [\varepsilon,B]$

[0,1]  $q_1 [0,B] \rightarrow q_3 [0,1] [0,B]$

[0,1]  $q_1 [1,B] \rightarrow q_3 [0,1] [1,B]$

[0,1]  $q_1 [\varepsilon,B] \rightarrow q_3 [0,1] [\varepsilon,B]$

[0,B]  $q_1 [0,B] \rightarrow q_3 [0,B] [0,B]$

[0,B]  $q_1 [1,B] \rightarrow q_3 [0,B] [1,B]$

[0,B]  $q_1 [\varepsilon,B] \rightarrow q_3 [0,B] [\varepsilon,B]$

[1,0]  $q_1 [0,B] \rightarrow q_3 [1,0] [0,B]$

[1,0]  $q_1 [1,B] \rightarrow q_3 [1,0] [1,B]$

[1,0]  $q_1 [\varepsilon,B] \rightarrow q_3 [1,0] [\varepsilon,B]$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

[1,1]  $q_1 [0,B] \rightarrow q_3 [1,1] [0,B]$

[1,1]  $q_1 [1,B] \rightarrow q_3 [1,1] [1,B]$

[1,1]  $q_1 [\varepsilon,B] \rightarrow q_3 [1,1] [\varepsilon,B]$

[1,B]  $q_1 [0,B] \rightarrow q_3 [1,B] [0,B]$

[1,B]  $q_1 [1,B] \rightarrow q_3 [1,B] [1,B]$

...



For transition  $\delta(q_2, 0) = (q_2, 0, R)$ :

$q_2 [0,0] \rightarrow [0,0] q_2$

$q_2 [1,0] \rightarrow [1,0] q_2$

$q_2 [\varepsilon,0] \rightarrow [\varepsilon,0] q_2$

For transition  $\delta(q_2, 1) = (q_2, 1, R)$ :

$q_2 [0,1] \rightarrow [0,1] q_2$

$q_2 [1,1] \rightarrow [1,1] q_2$

$q_2 [\varepsilon,1] \rightarrow [\varepsilon,1] q_2$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

6)  $q [a, X] \rightarrow [a, Y] p$

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

For transition  $\delta(q_2, B) = (q_4, B, L)$ :

$$[0,0] q_2 [0,B] \rightarrow q_4 [0,0] [0,B]$$

$$[0,0] q_2 [1,B] \rightarrow q_4 [0,0] [1,B]$$

$$[0,0] q_2 [\varepsilon,B] \rightarrow q_4 [0,0] [\varepsilon,B]$$

$$[0,1] q_2 [0,B] \rightarrow q_4 [0,1] [0,B]$$

$$[0,1] q_2 [1,B] \rightarrow q_4 [0,1] [1,B]$$

$$[0,1] q_2 [\varepsilon,B] \rightarrow q_4 [0,1] [\varepsilon,B]$$

$$[0,B] q_2 [0,B] \rightarrow q_4 [0,B] [0,B]$$

$$[0,B] q_2 [1,B] \rightarrow q_4 [0,B] [1,B]$$

$$[0,B] q_2 [\varepsilon,B] \rightarrow q_4 [0,B] [\varepsilon,B]$$

$$[1,0] q_2 [0,B] \rightarrow q_4 [1,0] [0,B]$$

$$[1,0] q_2 [1,B] \rightarrow q_4 [1,0] [1,B]$$

$$[1,0] q_2 [\varepsilon,B] \rightarrow q_4 [1,0] [\varepsilon,B]$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$[1,1] q_2 [0,B] \rightarrow q_4 [1,1] [0,B]$$

$$[1,1] q_2 [1,B] \rightarrow q_4 [1,1] [1,B]$$

$$[1,1] q_2 [\varepsilon,B] \rightarrow q_4 [1,1] [\varepsilon,B]$$

$$[1,B] q_2 [0,B] \rightarrow q_4 [1,B] [0,B]$$

$$[1,B] q_2 [1,B] \rightarrow q_4 [1,B] [1,B]$$

...



$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

For transition  $\delta(q_3, 0) = (q_5, B, L)$ :

- [0,0]  $q_3$  [0,0]  $\rightarrow$   $q_5$  [0,0] [0,B]
- [0,0]  $q_3$  [1,0]  $\rightarrow$   $q_5$  [0,0] [1,B]
- [0,0]  $q_3$  [ $\varepsilon$ ,0]  $\rightarrow$   $q_5$  [0,0] [ $\varepsilon$ ,B]
- [0,1]  $q_3$  [0,0]  $\rightarrow$   $q_5$  [0,1] [0,B]
- [0,1]  $q_3$  [1,0]  $\rightarrow$   $q_5$  [0,1] [1,B]
- [0,1]  $q_3$  [ $\varepsilon$ ,0]  $\rightarrow$   $q_5$  [0,1] [ $\varepsilon$ ,B]
- [0,B]  $q_3$  [0,0]  $\rightarrow$   $q_5$  [0,B] [0,B]
- [0,B]  $q_3$  [1,0]  $\rightarrow$   $q_5$  [0,B] [1,B]
- [0,B]  $q_3$  [ $\varepsilon$ ,0]  $\rightarrow$   $q_5$  [0,B] [ $\varepsilon$ ,B]
- [1,0]  $q_3$  [0,0]  $\rightarrow$   $q_5$  [1,0] [0,B]
- [1,0]  $q_3$  [1,0]  $\rightarrow$   $q_5$  [1,0] [1,B]
- [1,0]  $q_3$  [ $\varepsilon$ ,0]  $\rightarrow$   $q_5$  [1,0] [ $\varepsilon$ ,B]

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

- [1,1]  $q_3$  [0,0]  $\rightarrow$   $q_5$  [1,1] [0,B]
- [1,1]  $q_3$  [1,0]  $\rightarrow$   $q_5$  [1,1] [1,B]
- [1,1]  $q_3$  [ $\varepsilon$ ,0]  $\rightarrow$   $q_5$  [1,1] [ $\varepsilon$ ,B]
- [1,B]  $q_3$  [0,0]  $\rightarrow$   $q_5$  [1,B] [0,B]
- [1,B]  $q_3$  [1,0]  $\rightarrow$   $q_5$  [1,B] [1,B]
- ...

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

For transition  $\delta(q_4, 1) = (q_5, B, L)$ :

$$[0,0] q_4 [0,1] \rightarrow q_5 [0,0] [0,B]$$

$$[0,0] q_4 [1,1] \rightarrow q_5 [0,0] [1,B]$$

$$[0,0] q_4 [\varepsilon, 1] \rightarrow q_5 [0,0] [\varepsilon, B]$$

$$[0,1] q_4 [0,1] \rightarrow q_5 [0,1] [0,B]$$

$$[0,1] q_4 [1,1] \rightarrow q_5 [0,1] [1,B]$$

$$[0,1] q_4 [\varepsilon, 1] \rightarrow q_5 [0,1] [\varepsilon, B]$$

$$[0,B] q_4 [0,1] \rightarrow q_5 [0,B] [0,B]$$

$$[0,B] q_4 [1,1] \rightarrow q_5 [0,B] [1,B]$$

$$[0,B] q_4 [\varepsilon, 1] \rightarrow q_5 [0,B] [\varepsilon, B]$$

$$[1,0] q_4 [0,1] \rightarrow q_5 [1,0] [0,B]$$

$$[1,0] q_4 [1,1] \rightarrow q_5 [1,0] [1,B]$$

$$[1,0] q_4 [\varepsilon, 1] \rightarrow q_5 [1,0] [\varepsilon, B]$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$[1,1] q_4 [0,1] \rightarrow q_5 [1,1] [0,B]$$

$$[1,1] q_4 [1,1] \rightarrow q_5 [1,1] [1,B]$$

$$[1,1] q_4 [\varepsilon, 1] \rightarrow q_5 [1,1] [\varepsilon, B]$$

$$[1,B] q_4 [0,1] \rightarrow q_5 [1,B] [0,B]$$

$$[1,B] q_4 [1,1] \rightarrow q_5 [1,B] [1,B]$$

...



$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

For transition  $\delta(q_5, 0) = (q_5, 0, L)$ :

- [0,0]  $q_5 [0,0] \rightarrow q_5 [0,0] [0,0]$
- [0,0]  $q_5 [1,0] \rightarrow q_5 [0,0] [1,0]$
- [0,0]  $q_5 [\varepsilon,0] \rightarrow q_5 [0,0] [\varepsilon,0]$
- [0,1]  $q_5 [0,0] \rightarrow q_5 [0,1] [0,0]$
- [0,1]  $q_5 [1,0] \rightarrow q_5 [0,1] [1,0]$
- [0,1]  $q_5 [\varepsilon,0] \rightarrow q_5 [0,1] [\varepsilon,0]$
- [0,B]  $q_5 [0,0] \rightarrow q_5 [0,B] [0,0]$
- [0,B]  $q_5 [1,0] \rightarrow q_5 [0,B] [1,0]$
- [0,B]  $q_5 [\varepsilon,0] \rightarrow q_5 [0,B] [\varepsilon,0]$
- [1,0]  $q_5 [0,0] \rightarrow q_5 [1,0] [0,0]$
- [1,0]  $q_5 [1,0] \rightarrow q_5 [1,0] [1,0]$
- [1,0]  $q_5 [\varepsilon,0] \rightarrow q_5 [1,0] [\varepsilon,0]$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

- [1,1]  $q_5 [0,0] \rightarrow q_5 [1,1] [0,0]$
- [1,1]  $q_5 [1,0] \rightarrow q_5 [1,1] [1,0]$
- [1,1]  $q_5 [\varepsilon,0] \rightarrow q_5 [1,1] [\varepsilon,0]$
- [1,B]  $q_5 [0,0] \rightarrow q_5 [1,0] [0,0]$
- [1,B]  $q_5 [1,0] \rightarrow q_5 [1,0] [1,0]$
- ...

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

For transition  $\delta(q_5, 1) = (q_5, 1, L)$ :

$$[0,0] q_5 [0,1] \rightarrow q_5 [0,0] [0,1]$$

$$[0,0] q_5 [1,1] \rightarrow q_5 [0,0] [1,1]$$

$$[0,0] q_5 [\varepsilon, 1] \rightarrow q_5 [0,0] [\varepsilon, 1]$$

$$[0,1] q_5 [0,1] \rightarrow q_5 [0,1] [0,1]$$

$$[0,1] q_5 [1,1] \rightarrow q_5 [0,1] [1,1]$$

$$[0,1] q_5 [\varepsilon, 1] \rightarrow q_5 [0,1] [\varepsilon, 1]$$

$$[0,B] q_5 [0,1] \rightarrow q_5 [0,B] [0,1]$$

$$[0,B] q_5 [1,1] \rightarrow q_5 [0,B] [1,1]$$

$$[0,B] q_5 [\varepsilon, 1] \rightarrow q_5 [0,B] [\varepsilon, 1]$$

$$[1,0] q_5 [0,1] \rightarrow q_5 [1,0] [0,1]$$

$$[1,0] q_5 [1,1] \rightarrow q_5 [1,0] [1,1]$$

$$[1,0] q_5 [\varepsilon, 1] \rightarrow q_5 [1,0] [\varepsilon, 1]$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$[1,1] q_5 [0,1] \rightarrow q_5 [1,1] [0,1]$$

$$[1,1] q_5 [1,1] \rightarrow q_5 [1,1] [1,1]$$

$$[1,1] q_5 [\varepsilon, 1] \rightarrow q_5 [1,1] [\varepsilon, 1]$$

$$[1,B] q_5 [0,1] \rightarrow q_5 [1,B] [0,1]$$

$$[1,B] q_5 [1,1] \rightarrow q_5 [1,B] [1,1]$$

...



6)

 $q [ a, X ] \rightarrow [ a, Y ] p$ 

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$6) \quad q [ a, X ] \rightarrow [ a, Y ] p$$

For transition  $\delta(q_5, B) = (q_0, B, R)$ :

$$q_5 [0, B] \rightarrow [0, B] q_0$$

$$q_5 [1, B] \rightarrow [1, B] q_0$$

$$q_5 [\varepsilon, B] \rightarrow [\varepsilon, B] q_0$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_p, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$$6) \quad q [ a, X ] \rightarrow [ a, Y ] p$$

For transition  $\delta(q_5, B) = (q_0, B, R)$ :

$$q_5 [0, B] \rightarrow [0, B] q_0$$

$$q_5 [1, B] \rightarrow [1, B] q_0$$

$$q_5 [\varepsilon, B] \rightarrow [\varepsilon, B] q_0$$

**Final transitions for sequence acceptance:**

$$[0,0] q_P \rightarrow q_P 0 q_P$$

$$[0,1] q_P \rightarrow q_P 0 q_P$$

$$[0,B] q_P \rightarrow q_P 0 q_P$$

$$[1,0] q_P \rightarrow q_P 1 q_P$$

$$[1,1] q_P \rightarrow q_P 1 q_P$$

$$[1,B] q_P \rightarrow q_P 1 q_P$$

$$[\varepsilon,0] q_P \rightarrow q_P$$

$$[\varepsilon,1] q_P \rightarrow q_P$$

$$[\varepsilon,B] q_P \rightarrow q_P$$

$$q_P$$

$$q_P [0,0] \rightarrow q_P 0 q_P$$

$$q_P [0,1] \rightarrow q_P 0 q_P$$

$$q_P [0,B] \rightarrow q_P 0 q_P$$

$$q_P [1,0] \rightarrow q_P 1 q_P$$

$$q_P [1,1] \rightarrow q_P 1 q_P$$

$$q_P [1,B] \rightarrow q_P 1$$

$$q_P [\varepsilon,0] \rightarrow q_P$$

$$q_P [\varepsilon,1] \rightarrow q_P$$

$$q_P [\varepsilon,B] \rightarrow q_P$$

$$q_P \rightarrow \varepsilon$$

|       | 0           | 1           | B           |
|-------|-------------|-------------|-------------|
| $q_0$ | $q_1, B, R$ | $q_2, B, R$ | $q_P, B, R$ |
| $q_1$ | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| $q_2$ | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| $q_3$ | $q_5, B, L$ | -           | -           |
| $q_4$ | -           | $q_5, B, L$ | -           |
| $q_5$ | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

**Method that requires the  
knowledge of the purpose of  
TM**

6)

$q [ a, X ] \rightarrow [ a, Y ] p$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

6)

$q [ a, X ] \rightarrow [ a, Y ] p$



## Initial productions:

$A_1 \rightarrow q_0 A_2$

$A_2 \rightarrow [0,0] A_2$

$A_2 \rightarrow [1,1] A_2$

$A_2 \rightarrow A_3$

$A_3 \rightarrow [\epsilon, B] A_3$

$A_3 \rightarrow \epsilon$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

6)

$q [ a, X ] \rightarrow [ a, Y ] p$

## Initial productions:

$A_1 \rightarrow q_0 A_2$

$A_2 \rightarrow [0,0] A_2$

$A_2 \rightarrow [1,1] A_2$

$A_2 \rightarrow A_3$

$A_3 \rightarrow [\epsilon, B] A_3$

$A_3 \rightarrow \epsilon$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

## Symbol combinations:

6)  $q [ a, X ] \rightarrow [ a, Y ] p$



## Initial productions:

$A_1 \rightarrow q_0 A_2$

$A_2 \rightarrow [0,0] A_2$

$A_2 \rightarrow [1,1] A_2$

$A_2 \rightarrow A_3$

$A_3 \rightarrow [\varepsilon, B] A_3$

$A_3 \rightarrow \varepsilon$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

Symbol combinations: { [0,0], [1,1], [0,B], [1,B], [ε,B] }

6)

$q [ a, X ] \rightarrow [ a, Y ] p$

## Initial productions:

$A_1 \rightarrow q_0 A_2$

$A_2 \rightarrow [0,0] A_2$

$A_2 \rightarrow [1,1] A_2$

$A_2 \rightarrow A_3$

$A_3 \rightarrow [\epsilon, B] A_3$

$A_3 \rightarrow \epsilon$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

Symbol combinations: { [0,0], [1,1], [0,B], [1,B], [ε,B] }

For transition  $\delta(q_0, 0) = (q_1, B, R)$ :

$q_0[0,0] \rightarrow [0,B]q_1$

6)

$q [ a, X ] \rightarrow [ a, Y ] p$

## Initial productions:

$A_1 \rightarrow q_0 A_2$

$A_2 \rightarrow [0,0] A_2$

$A_2 \rightarrow [1,1] A_2$

$A_2 \rightarrow A_3$

$A_3 \rightarrow [\varepsilon, B] A_3$

$A_3 \rightarrow \varepsilon$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

Symbol combinations: { [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] }

For transition  $\delta(q_0, 0) = (q_1, B, R)$ :

$q_0[0,0] \rightarrow [0,B]q_1$

For transition  $\delta(q_0, 1) = (q_2, B, R)$ :

$q_0[1,1] \rightarrow [1,B]q_2$

6)

$q [ a, X ] \rightarrow [ a, Y ] p$

## Initial productions:

$A_1 \rightarrow q_0 A_2$

$A_2 \rightarrow [0,0] A_2$

$A_2 \rightarrow [1,1] A_2$

$A_2 \rightarrow A_3$

$A_3 \rightarrow [\varepsilon, B] A_3$

$A_3 \rightarrow \varepsilon$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

Symbol combinations: { [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] }

For transition  $\delta(q_0, 0) = (q_1, B, R)$ :

$q_0[0,0] \rightarrow [0,B]q_1$

For transition  $\delta(q_0, 1) = (q_2, B, R)$ :

$q_0[1,1] \rightarrow [1,B]q_2$

For transition  $\delta(q_0, B) = (q_P, B, R)$ :

$q_0[0,B] \rightarrow [0,B]q_P$

$q_0[1,B] \rightarrow [1,B]q_P$

$q_0[\varepsilon,B] \rightarrow [\varepsilon,B]q_P$

6)

$q [ a, X ] \rightarrow [ a, Y ] p$

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

{ [0,0], [1,1], [0,B], [1,B], [ $\varepsilon$ ,B] }

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] }

For transition  $\delta(q_1, 0) = (q_1, 0, R)$ :

$q_1[0,0] \rightarrow [0,B]q_1$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] }

For transition  $\delta(q_1, 0) = (q_1, 0, R)$ :

$q_1[0,0] \rightarrow [0,B]q_1$

For transition  $\delta(q_1, 1) = (q_1, 1, R)$ :

$q_1[1,1] \rightarrow [1,B]q_1$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

$$\delta( q, X ) = ( p, Y, L )$$

7)

$$[ b, Z ] q [ a, X ] \rightarrow p [ b, Z ] [ a, Y ]$$

$\{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] \}$

For transition  $\delta(q_1,0)=(q_1,0,R)$ :

$$q_1[0,0] \rightarrow [0,B]q_1$$

For transition  $\delta(q_1,1)=(q_1,1,R)$ :

$$q_1[1,1] \rightarrow [1,B]q_1$$

For transition  $\delta(q_1,B)=(q_3,B,L)$ :

$$[0,0]q_1[0,B] \rightarrow q_3[0,0][0,B]$$

$$[0,0]q_1[1,B] \rightarrow q_3[0,0][1,B]$$

$$[0,0]q_1[\varepsilon,B] \rightarrow q_3[0,0][\varepsilon,B]$$

$$[1,1]q_1[0,B] \rightarrow q_3[1,1][0,B]$$

$$[1,1]q_1[1,B] \rightarrow q_3[1,1][1,B]$$

$$[1,1]q_1[\varepsilon,B] \rightarrow q_3[1,1][\varepsilon,B]$$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

$$[0,B]q_1[0,B] \rightarrow q_3[0,B][0,B]$$

$$[0,B]q_1[1,B] \rightarrow q_3[0,B][1,B]$$

$$[0,B]q_1[\varepsilon,B] \rightarrow q_3[0,B][\varepsilon,B]$$

$$[1,B]q_1[0,B] \rightarrow q_3[1,B][0,B]$$

$$[1,B]q_1[1,B] \rightarrow q_3[1,B][1,B]$$

$$[1,B]q_1[\varepsilon,B] \rightarrow q_3[1,B][\varepsilon,B]$$



$\{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] \}$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

{ [0,0], [1,1], [0,B], [1,B], [ $\varepsilon$ ,B] }

For transition  $\delta(q_2, 0) = (q_2, 0, R)$ :

$q_2[0,0] \rightarrow [0,0]q_2$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

$\{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] \}$

For transition  $\delta(q_2,0)=(q_2,0,R)$ :

$q_2[0,0] \rightarrow [0,0]q_2$

For transition  $\delta(q_2,1)=(q_2,1,R)$ :

$q_2[1,1] \rightarrow [1,1]q_2$

|    | 0           | 1           | B           |
|----|-------------|-------------|-------------|
| q0 | $q_1, B, R$ | $q_2, B, R$ | $q_P, B, R$ |
| q1 | $q_1, 0, R$ | $q_1, 1, R$ | $q_3, B, L$ |
| q2 | $q_2, 0, R$ | $q_2, 1, R$ | $q_4, B, L$ |
| q3 | $q_5, B, L$ | -           | -           |
| q4 | -           | $q_5, B, L$ | -           |
| q5 | $q_5, 0, L$ | $q_5, 1, L$ | $q_0, B, R$ |

$\{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] \}$

For transition  $\delta(q_2, 0) = (q_2, 0, R)$ :

$q_2[0,0] \rightarrow [0,0]q_2$

For transition  $\delta(q_2, 1) = (q_2, 1, R)$ :

$q_2[1,1] \rightarrow [1,1]q_2$

For transition  $\delta(q_2, B) = (q_4, B, L)$ :

$[0,0]q_2[0,B] \rightarrow q_4[0,0][0,B]$

$[0,0]q_2[1,B] \rightarrow q_4[0,0][1,B]$

$[0,0]q_2[\varepsilon,B] \rightarrow q_4[0,0][\varepsilon,B]$

$[1,1]q_2[0,B] \rightarrow q_4[1,1][0,B]$

$[1,1]q_2[1,B] \rightarrow q_4[1,1][1,B]$

$[1,1]q_2[\varepsilon,B] \rightarrow q_4[1,1][\varepsilon,B]$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

$[0,B]q_2[0,B] \rightarrow q_4[0,B][0,B]$

$[0,B]q_2[1,B] \rightarrow q_4[0,B][1,B]$

$[0,B]q_2[\varepsilon,B] \rightarrow q_4[0,B][\varepsilon,B]$

$[1,B]q_2[0,B] \rightarrow q_4[1,B][0,B]$

$[1,B]q_2[1,B] \rightarrow q_4[1,B][1,B]$

$[1,B]q_2[\varepsilon,B] \rightarrow q_4[1,B][\varepsilon,B]$



$\{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] \}$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

$\{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] \}$

For transition  $\delta(q_3, 0) = (q_5, B, L)$ :

$[0,0]q_3[0,0] \rightarrow q_5[0,0][0,B]$

$[1,1]q_3[0,0] \rightarrow q_5[1,1][0,B]$

$[0,B]q_3[0,0] \rightarrow q_5[0,B][0,B]$

$[1,B]q_3[0,0] \rightarrow q_5[1,B][0,B]$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

$\{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] \}$

For transition  $\delta(q_3, 0) = (q_5, B, L)$ :

$[0,0]q_3[0,0] \rightarrow q_5[0,0][0,B]$

$[1,1]q_3[0,0] \rightarrow q_5[1,1][0,B]$

$[0,B]q_3[0,0] \rightarrow q_5[0,B][0,B]$

$[1,B]q_3[0,0] \rightarrow q_5[1,B][0,B]$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

For transition  $\delta(q_4, 1) = (q_5, B, L)$ :

$[0,0]q_4[1,1] \rightarrow q_5[0,0][1,B]$

$[1,1]q_4[1,1] \rightarrow q_5[1,1][1,B]$

$[0,B]q_4[1,1] \rightarrow q_5[0,B][1,B]$

$[1,B]q_4[1,1] \rightarrow q_5[1,B][1,B]$

$\{ [0,0], [1,1], [0,B], [1,B], [\varepsilon,B] \}$

For transition  $\delta(q_3, 0) = (q_5, B, L)$ :

$[0,0]q_3[0,0] \rightarrow q_5[0,0][0,B]$

$[1,1]q_3[0,0] \rightarrow q_5[1,1][0,B]$

$[0,B]q_3[0,0] \rightarrow q_5[0,B][0,B]$

$[1,B]q_3[0,0] \rightarrow q_5[1,B][0,B]$

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

For transition  $\delta(q_4, 1) = (q_5, B, L)$ :

$[0,0]q_4[1,1] \rightarrow q_5[0,0][1,B]$

$[1,1]q_4[1,1] \rightarrow q_5[1,1][1,B]$

$[0,B]q_4[1,1] \rightarrow q_5[0,B][1,B]$

$[1,B]q_4[1,1] \rightarrow q_5[1,B][1,B]$

For transition  $\delta(q_5, 0) = (q_5, 0, L)$ :

$[0,0]q_5[0,0] \rightarrow q_5[0,0][0,0]$

$[1,1]q_5[0,0] \rightarrow q_5[1,1][0,0]$

$[0,B]q_5[0,0] \rightarrow q_5[0,B][0,0]$

$[1,B]q_5[0,0] \rightarrow q_5[1,B][0,0]$



|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

For transition  $\delta(q_5, 1) = (q_5, 1, L)$ :

[0,0]q<sub>5</sub>[1,1] → q<sub>5</sub>[0,0][1,1]

[1,1]q<sub>5</sub>[1,1] → q<sub>5</sub>[1,1][1,1]

[0,B]q<sub>5</sub>[1,1] → q<sub>5</sub>[0,B][1,1]

[1,B]q<sub>5</sub>[1,1] → q<sub>5</sub>[1,B][1,1]

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

For transition  $\delta(q_5, 1) = (q_5, 1, L)$ :

[0,0]q<sub>5</sub>[1,1] → q<sub>5</sub>[0,0][1,1]

[1,1]q<sub>5</sub>[1,1] → q<sub>5</sub>[1,1][1,1]

[0,B]q<sub>5</sub>[1,1] → q<sub>5</sub>[0,B][1,1]

[1,B]q<sub>5</sub>[1,1] → q<sub>5</sub>[1,B][1,1]

For transition  $\delta(q_5, B) = (q_0, B, R)$ :

q<sub>5</sub>[0,B] → [0,B]q<sub>0</sub>

q<sub>5</sub>[1,B] → [1,B]q<sub>0</sub>

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

For transition  $\delta(q_5, 1) = (q_5, 1, L)$ :

[0,0]q<sub>5</sub>[1,1] → q<sub>5</sub>[0,0][1,1]

[1,1]q<sub>5</sub>[1,1] → q<sub>5</sub>[1,1][1,1]

[0,B]q<sub>5</sub>[1,1] → q<sub>5</sub>[0,B][1,1]

[1,B]q<sub>5</sub>[1,1] → q<sub>5</sub>[1,B][1,1]

For transition  $\delta(q_5, B) = (q_0, B, R)$ :

q<sub>5</sub>[0,B] → [0,B]q<sub>0</sub>

q<sub>5</sub>[1,B] → [1,B]q<sub>0</sub>

|    | 0        | 1        | B        |
|----|----------|----------|----------|
| q0 | q1, B, R | q2, B, R | qP, B, R |
| q1 | q1, 0, R | q1, 1, R | q3, B, L |
| q2 | q2, 0, R | q2, 1, R | q4, B, L |
| q3 | q5, B, L | -        | -        |
| q4 | -        | q5, B, L | -        |
| q5 | q5, 0, L | q5, 1, L | q0, B, R |

Final transitions for sequence acceptance:

[0,B]qP → qP0qP

qP[0,B] → qP0qP

qP → ε

[1,B]qP → qP1qP

qP[1,B] → qP1qP

[ε,B]qP → qP

qP[ε,B] → qP