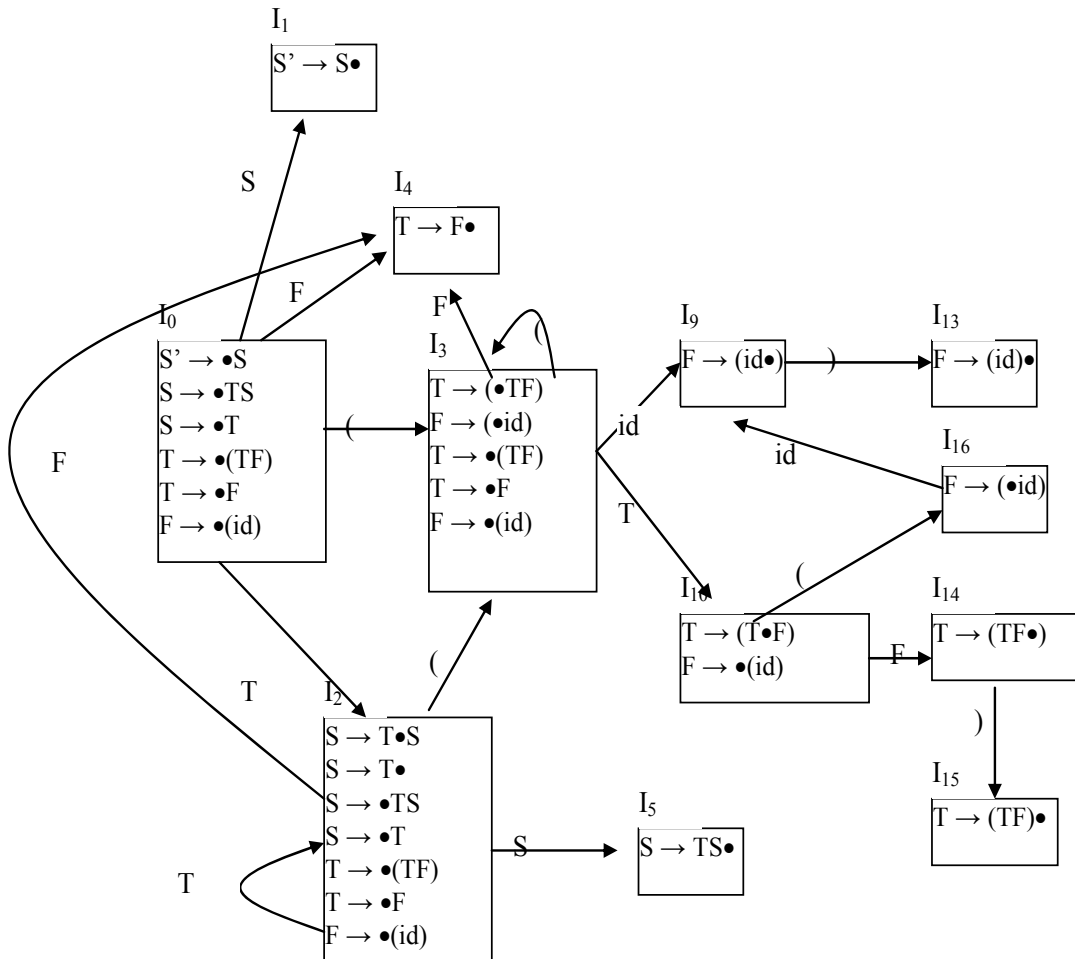


1. Consider the following grammar. Note that id, (, and) are terminals.

$S \rightarrow TS \mid T$
 $T \rightarrow (TF) \mid F$
 $F \rightarrow (id)$

(a) Construct the LR(0) DFA for the grammar.



(b) Construct the SLR parsing table for the grammar.

$\text{Follow}(S) = \{\$ \}$
 $\text{Follow}(T) = \{\$, (\}$
 $\text{Follow}(F) = \{\$, (,) \}$

	(	)	id	\$	S	T	F
0	3				1	2	4
1				Acc			
2	3			$S \rightarrow T$	5	2	4
3	3		9			10	4
4	$T \rightarrow F$			$T \rightarrow F$			

5				S→TS			
9		13					
10	16						14
13	F→(id)	F→(id)		F→(id)			
14		15					
15	T→(TF)			T→(TF)			
16			9				

(c) Parse the string (((id)(id))(id))(id). Show the stack, the input, and the action taken.

Stack	Input	Action
0	(((id)(id))(id))(id)\$	S3
0 (3	((id)(id))(id))(id) \$	S3
0 (3 (3	(id)(id))(id))(id) \$	S3
0 (3 (3 (3	id)(id))(id))(id) \$	S9
0 (3 (3 (3 id 9	)(id))(id))(id) \$	S13
0 (3 (3 (3 id 9) 13	(id))(id))(id) \$	F→(id) Goto(3, F) = 4
0 (3 (3 F 4	(id))(id))(id) \$	T→F Goto(3, T) = 10
0 (3 (3 T 10	(id))(id))(id) \$	S16
0 (3 (3 T 10 (16	id))(id))(id) \$	S9
0 (3 (3 T 10 (16 id 9	))(id))(id) \$	S13
0 (3 (3 T 10 (16 id 9) 13	)(id))(id) \$	F→(id) Goto(10, F) = 14
0 (3 (3 T 10 F 14	)(id))(id) \$	S15
0 (3 (3 T 10 F 14) 15	(id))(id) \$	T→(TF) Goto(3, T) = 10
0 (3 T 10	(id))(id) \$	S16
0 (3 T 10 (16	id))(id) \$	S9
0 (3 T 10 (16 id 9	))(id) \$	S13
0 (3 T 10 (16 id 9) 13	)(id) \$	F→(id) Goto(10, F) = 14
0 (3 T 10 F 14	)(id) \$	S15
0 (3 T 10 F 14) 15	(id) \$	T→(TF) Goto(0, T) = 2
0 T 2	(id) \$	S3
0 T 2 (3	id) \$	S9
0 T 2 (3 id 9	) \$	S13
0 T 2 (3 id 9) 13	\$	F→(id) Goto(2, F) = 4
0 T 2 F 4	\$	T→F Goto(2, T) = 2
0 T 2 T 2	\$	S→T Goto(2, S) = 5
0 T 2 S 5	\$	S→TS Goto(0, S) = 1
0 S 1	\$	Accept

2. Consider the following grammar.

$S \rightarrow A-B)$

$A \rightarrow B \mid a)$

$B \rightarrow aB \mid a$

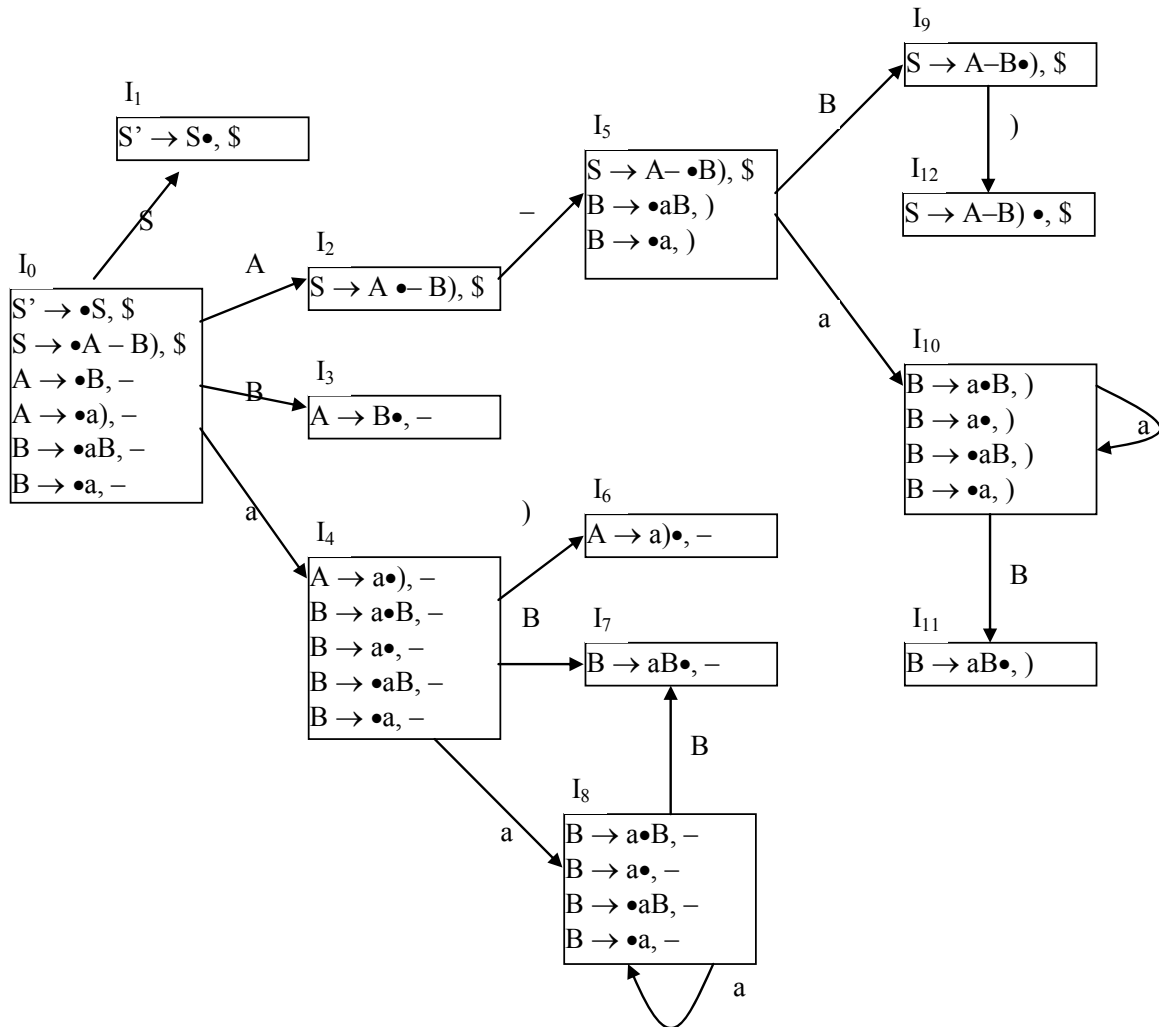
(b) Construct the LR(1) Automata for the grammar.

$S' \rightarrow S$

$S \rightarrow A - B)$

$A \rightarrow B \mid a)$

$B \rightarrow aB \mid a$



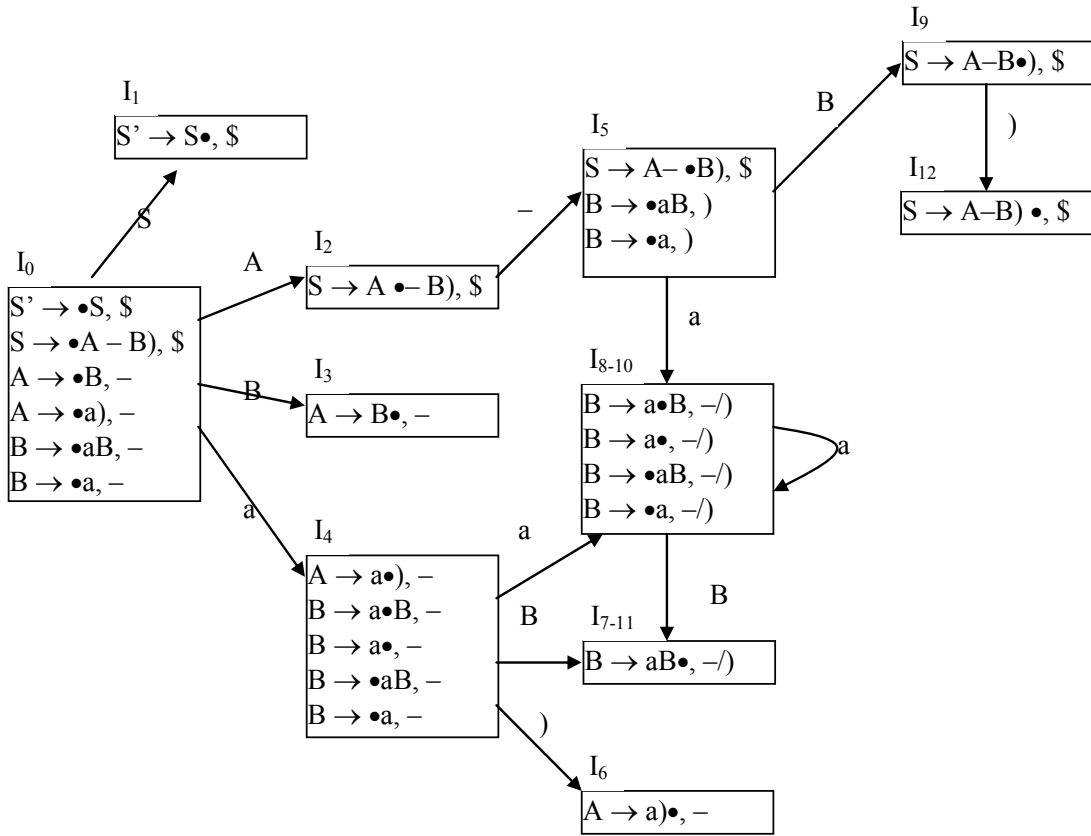
(c) Construct the LR parsing table for the grammar.

	a	-	)	\$	S	A	B
0	4				1	2	3
1				Acc			
2		5					
3		A → B					
4	8	B → a	6				7
5	10						9
6		A → a)					
7		B → aB					
8	8	B → a					7
9			12				
10	10		B → a				11
11			B → aB				
12				S → A-B)			

(d) Parse the string a)-aaa). Show the stack, the input, and the action taken.

Stack	input	comment
0	a)-aaa)\$	S4
0 a 4	)-aaa)\$	S6
0 a 4) 6	-aaa)\$	A → a) A[0, A] = S2
0 A 2	-aaa)\$	S5
0 A 2 - 5	aaa)\$	S10
0 A 2 - 5 a 10	aa)\$	S10
0 A 2 - 5 a 10 a 10	a)\$	S10
0 A 2 - 5 a 10 a 10 a 10	)\$	B → a A(10, B) = 11
0 A 2 - 5 a 10 a 10 B 11	)\$	B → aB A(10, B) = 11
0 A 2 - 5 a 10 B 11	)\$	B → aB A(5, B) = S9
0 A 2 - 5 B 9	)\$	S12
0 A 2 - 5 B 9) 12	\$	S → A - B) A(0, S) = S1
0 S 1	\$	Acc

(e) Merge the LR(1) states and convert the LR(1) automata to LALR(1).



(a) Show that the grammar is not SLR(1).

Follow(S) = { $\$$ }

Follow(A) = { $\$$, $-$ }

Follow(B) = { $\$$, $-$, $)$ }

	a	-	)	\$	S	A	B
0	4				1	2	3
1				Acc			
2		5					
3		A → B		A → B			
4	8-10		6 B → a				7-11

3. Give example grammars for the following specifications.

(a) A grammar that is not SLR(5) but is SLR(6).

$$\begin{aligned} S &\rightarrow A b^5 c \mid B b^5 d \\ A &\rightarrow a \\ B &\rightarrow a \end{aligned}$$

(b) A grammar that is LR(1), not LALR(1), and is LALR(2).

$$\begin{aligned} S &\rightarrow aAdx \mid bBdy \mid bAeu \mid aBev \\ A &\rightarrow c \\ B &\rightarrow c \end{aligned}$$

4. Consider the following grammar for a very small csh-like language.

$$\begin{aligned} P &\rightarrow S; P \mid S; \\ S &\rightarrow A \mid R \mid F \\ A &\rightarrow \text{id} := E \\ E &\rightarrow E + \text{id} \mid \text{id} \mid O \mid (M) \\ R &\rightarrow \mathbf{print} \text{id} \\ F &\rightarrow \mathbf{foreach} \text{id} \mathbf{in} L \mathbf{do} \{ P \} \\ L &\rightarrow (M) \mid \text{id} \\ M &\rightarrow MO \mid \varepsilon \\ O &\rightarrow \text{string} \mid \text{integer} \end{aligned}$$

A program consists of a sequence of statements. A statement can be an assignment statement (A), a print statement (R), or a foreach loop statement (F). The foreach loop has a loop list L. L is a list of objects which can be a string, an integer, or a real number. L can be an id of type “list” or can be an actual list of objects enclosed in (). In each iteration, an object from the loop list is assigned to the loop identifier (id) and P is executed. The following is a sample program for this csh-like language.

```
total := 0;
count := 0;
objList1 := (11 15 302 287 19 8);
objList2 := (15 87 66 78);
objList := objList1 + objList2;
foreach num in objList do
  { totoal := total + num;
    count := count + 1;
  }
print objList;
print total;
```

This language does not require variable declaration, but it does have a few semantic rules.

- (i) In the list (M), all objects should be of the same type, either all strings or all integers.
- (ii) The loop identifier should not be modified in the loop body.
- (iii) There should be at most two levels of nested foreach loops.

(a) Use attributed grammar to check the semantic rules given above. In other words, you should add attribute rules to the given grammar. Only inherited and synthesized attributes are allowed, no global attributes.

$P \rightarrow S; P_1$	$P.level := \max(P_1.level, S.level)$ $P.normalIDs := S.normalIDs \cup P_1.normalIDs$
$P \rightarrow S;$	$P.level := S.level;$ $P.normalIDs := S.normalIDs;$
$S \rightarrow A$	$S.level := 0$ $S.normalIDs := A.normalIDs$
$S \rightarrow R$	$S.level := 0$ $S.normalIDs := \{ \}$
$S \rightarrow F$	$S.level := F.level$ $S.normalIDs := F.normalIDs$
$A \rightarrow id := E$	$A.normalIDs := \{id\}$
$E \rightarrow E + id$	
$E \rightarrow id$	
$E \rightarrow O$	
$E \rightarrow (M)$	
$R \rightarrow \mathbf{print} \ id$	
$F \rightarrow \mathbf{foreach} \ id \ \mathbf{in} \ L \ \mathbf{do} \ \{ P \}$	$F.level := P.level + 1;$ If $F.level > 2$ then error; If $id \in P.normalIDs$ then error Else $F.normalIDs := \{id\} \cup P.normalIDs;$
$L \rightarrow (M)$	
$L \rightarrow id$	
$M \rightarrow MO$	If $(M.type == void)$ then $M.type = O.type$ else if $(M.type != O.type)$ then type error
$M \rightarrow \epsilon$	$M.type = void$
$O \rightarrow string$	$O.type := string$
$O \rightarrow integer$	$O.type := integer$

(b) If your attributed grammar can be evaluated during parsing without an additional evaluation phase, then briefly discuss how it is possible. If your grammar cannot be evaluated at the parsing phase, then use the techniques we have introduced to modify your attributed grammar or the original grammar so that the semantic analysis can be done with parsing.

Because the attribute rules above are all synthesized rules, they can be evaluated during parsing without an additional evolution.

5. Consider the following attribute grammar for code generation for array references (the attribute grammar is not pure, it uses global variables).

The newtemp function returns a new temporary variable name. The name consists of a leading character t and a number. For the i-th call, the number is i. In other words, the temporary variables generated by a sequence of call to newtemp function are: t1, t2, t3,

The lookup function searches the symbol table to find the corresponding id entry. The input to the function is the name of the identifier and the field of the entry to be retrieved. The field arrayInfo of an array identifier stores all the definitions of the corresponding array. The field arrayInfo.arraySize is an array storing the maximum sizes of all the dimensions of the array. The field arrayInfo.elementWidth is the size of each element in the array.

```

S → L := E          { if (L.array = true and E.array = false) then
                      emit (L.place '[' L.offset ']' := E.place); ... }
L → A                { L.array := true; L.offset := A.offset;
                      L.place := A.place; }
A → Elist]           { A.place := arrayPlace; A.offset := offset;
                      emit (offset := offset * elementWidth; }
Elist → Elist1, E   { Elist.dim := Elist1.dim + 1;
                      emit (offset := offset * arraySize[Elist.dim]);
                      emit (offset := offset + E.place; }
Elist → id[E         { Elist.dim := 0;
                      arrayPlace := lookup(id.name);
                      offset := newtemp();
                      p := lookup (id.name, arrayInfo);
                      arraySize := p.arraySize;
                      elementWidth := p.elementWidth;
                      emit (offset := E.place); }
E → id                { E.place := lookup(id.name); }
E → num               { E.place := num; }

```

Consider a given input statement: “member[w, x, y, z] := 103”. Follow the attribute grammar above and generate the three address code. A statement of the three address code may look like, for example: “t1 := x + y”.

```

t1 := w;
t1 := t1 * arraySize[1];
t1 := t1 + x;
t1 := t1 * arraySize[2];
t1 := t1 + y;
t1 := t1 * arraySize[3];
t1 := t1 + z;
t1 := t1 * elementWidth;
member[t1] = 103;

```