COMPILER LECTURES

COMPUTER SCIENCE

3RD CLASS

M.SC. SAMER AL-YASSIN

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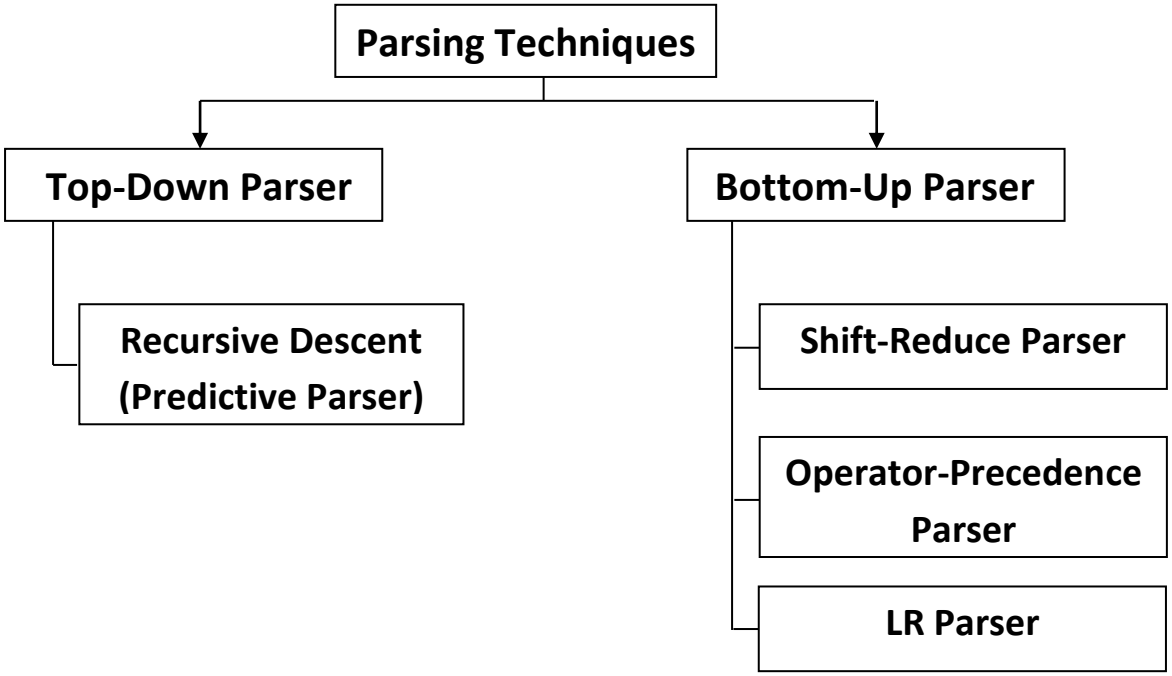
LECTURE 6

Parsing Techniques

Parsers

A ***parser*** for grammar ***G*** is a program that takes as input a string ***w*** and produces as output either a parse tree for ***w***, if ***w*** is a sentence of ***G***, or an error message indicating that ***w*** is not a sentence of ***G***.

There are two basic types of **parsers** for context-free grammars are **Top-Down** and **Bottom-Up**. As indicated by their names, top-down parsers start with the root and work down to the leaves, while bottom-up parsers build parse trees from the bottom (leaves) to the top (root). In both cases the input to the parser is being scanned from ***left to right***, one symbol at a time.



Top-Down Parsing

Top-down parsing can be viewed as an attempt to find a ***leftmost derivation*** for an input string. Equivalently, it can be viewed as an attempt to construct a parse tree for the input starting from the root and creating the nodes of the parse tree in preorder.

Recursive-Descent Parsing

The general form of top-down parsing, called recursive descent, the recursive descent can be divided to two cases. First case that may involve **Backtracking**, which is, making repeated scans of the input and second case, is **No Backtracking** (***Predictive Parser***).

Backtracking

Backtracking is required in the next example, and will be keeping track of the input when backtracking takes place.

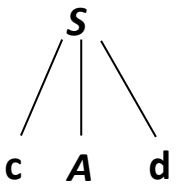
Example: Consider the grammar

$S \longrightarrow cAd$

$A \longrightarrow ab \mid a$

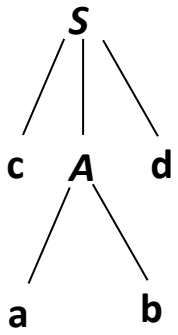
and the input string w = **cad**. To construct a parse tree for this string top-down.

1) Create a tree consisting of a single node labeled ***S***.
2) An input pointer points to **c**, the first symbol of ***w***. We then use the first production for ***S*** to expand the tree and obtain the tree of Figure below.



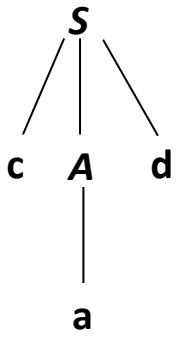
The leftmost leaf, labeled **c**, matches the first symbol of ***w***.

3) Advance the input pointer to **a**, the second symbol of ***w***, and consider the next leaf, labeled ***A***. We can then expand ***A*** using the first alternative for ***A*** to obtain the tree of Figure below. We now have a match for the second input symbol.



4) Advance the input pointer to **d**, the third input symbol, and compare **d** against the next leaf, labeled **b**. Since **b** does not match **d**, we report failure and **go back to *A*** to see whether there is another alternative for ***A*** that we have not tried but that might produce a match.

5) In going back to ***A***, we must reset the input pointer to position **2**, the position it had when we first came to ***A***, we now try the second alternative for ***A*** to obtain the tree of figure below.



The leaf **a** matches the second symbol of ***w*** and the leaf **d** matches the third symbol. Since we have produced a parse tree for ***w***, we halt and announce successful completion of parsing.

Note: A left-recursive grammar can cause a recursive-descent parser, even one with backtracking, to go into an infinite loop. That is, when we try to expand ***A***, we may eventually find ourselves again trying to expand ***A*** without having consumed any input.

Predictive Parser

In many cases, by carefully writing a grammar, ***eliminating left recursion*** from it, and ***left factoring*** the resulting grammar, we can obtain a grammar that can be parsed by a **recursive-descent parser** that needs **no backtracking**, i.e., a **predictive parser**.

☒ Transition Diagrams for Predictive Parser

We can create a transition diagram as a plan for a predictive parser.

Several differences between the transition diagrams for a lexical analyzer and a predictive parser are immediately apparent. In the case of the parser, there is one diagram for each **nonterminal**. The labels of edges are **tokens** (**terminal**) and **nonterminals**. A transition on a token (**terminal**) means we should take that transition if that token is the next input symbol. A transition on a nonterminal, ***A*** is a call of the procedure for ***A***.

To construct the transition diagram *of a predictive parser from a grammar, first* ***eliminate left recursion*** *from the grammar, and then* ***left factor*** *the grammar. Then for each* ***nonterminal A*** *do the following:*

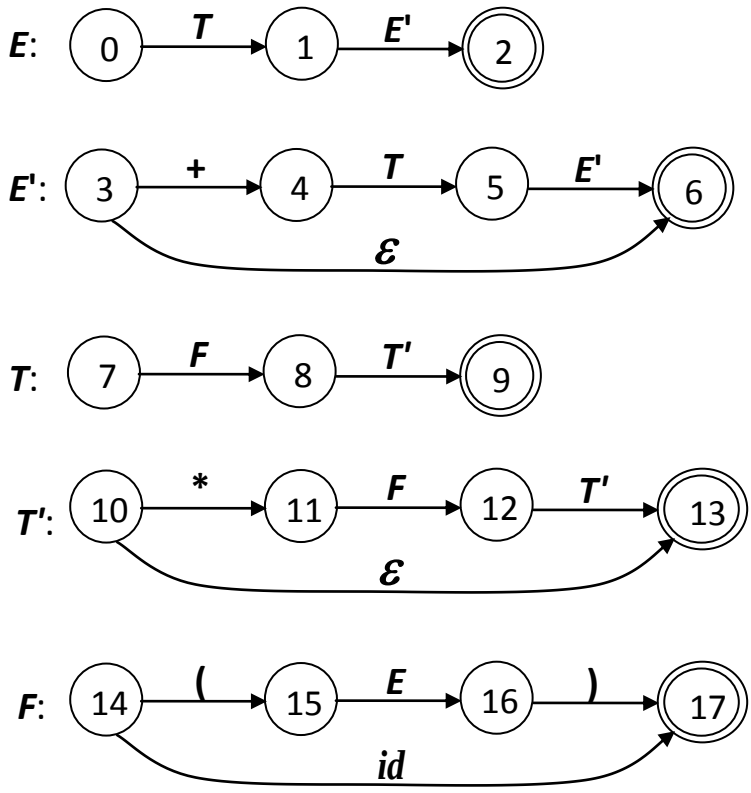
1) Create an **initial** and **final** (return) state.
2) For each production $A \longrightarrow X_1X_2 \ldots X_n$, create a **path** from the **initial** to the **final** state, with edges labeled $X_1X_2 \ldots X_n$.

The predictive parser working off the transition diagrams behaves as follows. It begins in the **start** state for the **start symbol**. If after some actions it is in state ***s*** with an edge labeled by terminal ***a*** to state ***t***, and if the next input symbol is ***a***, then the parser moves the

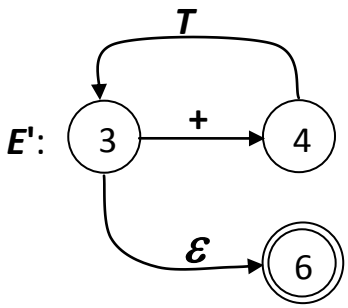
input cursor one position right and goes to state ***t***. If, on the other hand, the edge is labeled by a nonterminal ***A***, the parser instead goes to the **start** state for ***A***, without moving the input cursor. If it ever reaches the **final** state for ***A***, it immediately goes to state ***t***, in effect having "read" ***A*** from the input during the time it moved from state **s** to ***t***. **Finally**, if there is an edge from ***s*** to ***t*** labeled ∈, then from state ***s*** the parser immediately goes to state ***t***, without advancing the input.

Example: Design the transition diagram of predictive parser for the following grammar:

$E \longrightarrow TE'$
$E' \longrightarrow +TE' \mid \in$
$T \longrightarrow FT'$
$T' \longrightarrow *FT' \mid \in$
$F \longrightarrow (E) \mid id$



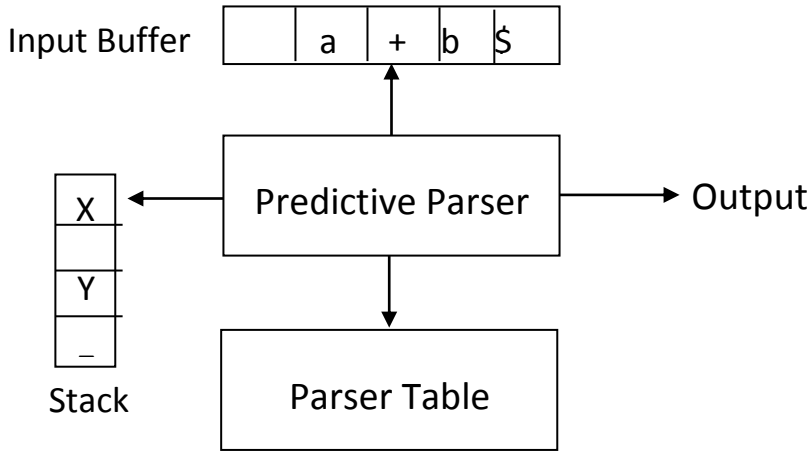
The figure in below shows an equivalent transition diagram for ***E'***.



Simplified Transition diagram

☒ Components of Predictive Parser

Predictive parser has an input buffer, a stack, a parsing table, and an output stream. The model of predictive parser is shown the in figure below:



Model of Predictive

1) The input buffer contains the string to be parsed, followed by **$**, a symbol used as a right endmarker to indicate the end of the input string.

2) The stack contains a sequence of grammar symbols with **$** on the bottom, indicating the bottom of the stack. Initially, the stack contains the start symbol of the grammar on top of **$**.
3) The parsing table is a **two-dimensional array *M [A, a]***, where ***A*** is a nonterminal, and ***a*** is a terminal or the symbol **$**.

The parser is controlled by a program that behaves as follows. The program considers ***X***, the symbol on top of the stack, and ***a***, the current input symbol. These two symbols determine the action of the parser. There are three possibilities.

a) If ***X* = a = $**, the parser halts and announces successful completion of parsing.

b) If ***X* = a ≠ $**, the parser pops ***X*** off the stack and advances the input pointer to the next input symbol.

c) If ***X*** is a nonterminal, the program consults entry ***M[X, a]*** of the parsing table ***M***. This entry will be either an ***X***-production of the grammar or an error entry. If, for example, ***M[X, a]*** = {$X \longrightarrow UVW$}, the parser replaces ***X*** on top of the stack by ***WVU*** (with ***U*** on top).

4) As output, we shall assume that the parser just prints the production used; any other code could be executed here. If M[X, a] = error, the parser calls error recovery routine.

☒ Construction of Predictive Parsing Tables

The following algorithm can be used to construct a predictive parsing table for a grammar ***G***.

Algorithm: Construction of a predictive parsing table.

Input: Grammar ***G***.

Output: Parsing table ***M***.

Method:

1. For each production $A \longrightarrow \alpha$ of the grammar, do steps 2 and 3.
2. For each terminal ***a*** in FIRST (**α**), add $A \longrightarrow \alpha$ to ***M [A,*** **a*****]***.
3. If ε is in FIRST (**α**), add $A \longrightarrow \alpha$ to ***M [A,*** **b*****]*** for each terminal **b** in FOLLOW (***A***). If ε is in FIRST (**α**) and $ is in FOLLOW (***A***), add $A \longrightarrow \alpha$ to ***M [A,*** **$*****]***.
4. Make each undefined entry of ***M*** be error.

Example: Parse the string **id + id * id** by using predictive parser for the following grammar:

$E \longrightarrow TE'$
$E' \longrightarrow +TE' \mid \in$
$T \longrightarrow FT'$
$T' \longrightarrow *FT' \mid \in$
$F \longrightarrow (E) \mid \mathbf{id}$

FIRST (***E***) = FIRST (***T***) = FIRST (***F***) = {**(, id}**

FIRST (***E'***) = {**+,** ∈**}**

FIRST (***T'***) = {***,** ∈**}**

FOLLOW (***E***) = FOLLOW (***E'***) = {), $}

FOLLOW (***T***) = FOLLOW (***T'***) = {+,), $}

FOLLOW (***F***) = {*, +,), $}

NONTER-MINALS	INPUT SYMBOL					
	id	+	*	(	)	$
E	$E \longrightarrow TE'$			$E \longrightarrow TE'$		
E'		$E' \longrightarrow +TE'$			$E' \longrightarrow \in$	$E' \longrightarrow \in$
T	$T \longrightarrow FT'$			$T \longrightarrow FT'$		
T'		$T' \longrightarrow \in$	$T' \longrightarrow *FT'$		$T' \longrightarrow \in$	$T' \longrightarrow \in$
F	$F \longrightarrow$ id			$F \longrightarrow (E)$		

Predictive Parsing Table *M* For Above Grammar

Stack	Input	Output
$ E	id + id * id$	
$ $E'T$	id + id * id$	$E \longrightarrow TE'$
$ $E'T'F$	id + id * id$	$T \longrightarrow FT'$
$ $E'T'$ id	id + id * id$	$F \longrightarrow$ id
$ $E'T'$	+ id * id$	
$ E'	+ id * id$	$T' \longrightarrow \varepsilon$
$ $E'T$+	+ id * id$	$E' \longrightarrow +TE'$
$ $E'T$	id * id$	
$ $E'T'F$	id * id$	$T \longrightarrow FT'$
$ $E'T'$ id	id * id$	$F \longrightarrow$ id
$ $E'T'$	* id$	
$ $E'T'F$*	* id$	$T' \longrightarrow *FT'$
$ $E'T'F$	id$	
$ $E'T'$ id	id$	$F \longrightarrow$ id
$ $E'T'$	$	
$ E'	$	$T' \longrightarrow \varepsilon$
$	$	$E' \longrightarrow \varepsilon$

Blanks are error entries; non-blanks indicate a production with which to expand the top nonterminal on the stack.

Moves made by predictive parser on input **id + id * id**

LL (1) Grammars

Algorithm construction of a predictive parsing table can be applied to any grammar ***G*** to produce a parsing table ***M***. For some grammars, however, ***M*** may have some entries that are **multiply-defined**. for example, if ***G*** is **left recursive** or **ambiguous**, then ***M*** will have at least one **multiply-defined** entry.

Example: Let us consider the following grammar:

$S \longrightarrow iEtSS' \mid a$
$S' \longrightarrow eS \mid \in$
$E \longrightarrow b$

FIRST (S) = {**i, a**}

FIRST (S') = {**e,** $\in$**}**

FIRST (E) = {**b**}

FOLLOW (S) = {**e**, $}

FOLLOW (S') = {**e**, $}

FOLLOW (E) = {t}

NONTER-MINALS	INPUT SYMBOL					
	a	b	e	i	t	$
S	$S \longrightarrow a$			$S \longrightarrow iEtSS'$		
S'			$S' \longrightarrow \in$ $S' \longrightarrow eS$			$S' \longrightarrow \in$
E		$E \longrightarrow b$				

The entry for ***M[S',e]*** contains both $S' \longrightarrow eS$ and $S' \longrightarrow \varepsilon$, since FOLLOW($S'$) = {**e,** $}. The grammar is **ambiguous** and the ambiguity is manifested by a choice in what production to use when an **e** is seen. **Therefore** this grammar is **not** LL (1).

Definition of LL (1):

A grammar whose parsing table has no multiply-defined entries is said to be LL (1). The **first** "L" in LL(1) stands for scanning the input from left to right, the **second** "L" for producing a leftmost derivation, and the "**1**" for using one input symbol of lookahead at each step to make parsing action decisions. LL (1) grammars have several distinctive properties. **No ambiguous** or **left- recursive** grammar can be LL (1).

The grammar is LL (1) if satisfy the following Conditions :

For all productions $A \longrightarrow \alpha_1 \mid \alpha_2 \mid \ldots\ldots \mid \alpha_n$

1. FIRST (α_i) ∩ FIRST (α_j) = ϕ for all $i \neq j$ and
2. If $\alpha_i \xrightarrow{*} \in$, Then FIRST ($\alpha_j$) ∩ FOLLOW($A$)= ϕ for all $i \neq j$

Example: Is the following grammar LL (1)?

$A \longrightarrow iBte$
$B \longrightarrow SB \mid \in$
$S \longrightarrow [ec] \mid \bullet i$

Sol:

Rule 1:

$B \longrightarrow SB \mid \in$
FIRST (SB) ∩ FIRST ($\in$) = {[, •} ∩ {$\in$} = ϕ

$S \longrightarrow [ec] \mid \bullet i$
FIRST ([ec]) ∩ FIRST (•i) = {[} ∩ {•} = ϕ

Rule 2:

$B \longrightarrow SB \mid \in$
FIRST (SB) ∩ FOLLOW (B) = {[, •} ∩ {t} = ϕ

This grammar is LL (1).

Example: Is the following grammar LL (1)?

$S \longrightarrow XS \mid aY$
$X \longrightarrow a \mid b$
$Y \longrightarrow (S)$

Sol:
Rule 1:

$S \longrightarrow XS \mid aY$
FIRST (XS) ∩ FIRST (aY) = {**a, b**} ∩ {**a**} = {**a**}

This grammar is **not LL (1)**. And it is not suitable for constructing parser table.

Example: Is the following grammar LL (1)?

$S \longrightarrow Aa \mid bB$
$A \longrightarrow aBmS \mid C$
$B \longrightarrow (S)$
$C \longrightarrow \in$

Sol:
Rule 1:

$S \longrightarrow Aa \mid bB$
FIRST (Aa) ∩ FIRST (bB) = {**a,** $\in$**}** ∩ {**b**} = ϕ
$A \longrightarrow aBmS \mid C$
FIRST ($aBmS$) ∩ FIRST (C) = {**a**} ∩ **{**$\in$**}** = ϕ

Rule 2:
$A \longrightarrow aBmS \mid C$ Since $C \longrightarrow \in$**,** Then

FIRST ($aBmS$) and FOLLOW (A) must be disjoint.

FIRST ($aBmS$) ∩ FOLLOW (A) = {**a**} ∩ {**a**} = {**a**}

This grammar is not LL (1).