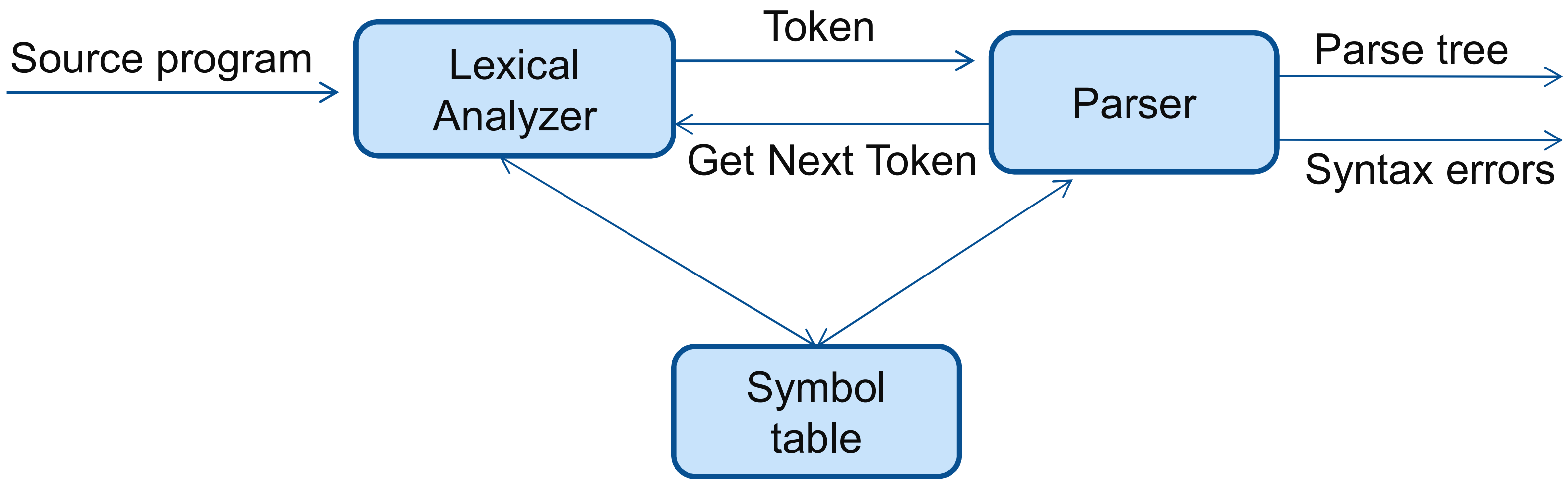
Syntax Analysis
(Part-1)

Role of Parser

- The parser obtains a string of tokens from the lexical analyzer and verifies that the string can be generated by the grammar for the source language to form a ***parse tree***.
- The parser provides report for any ***syntax errors*** in an intelligible fashion. It should also recover from commonly occurring errors so that it can continue processing the remainder of its input.



Error Handling

- The programmers frequently write incorrect programs, and a good compiler should assist the programmer in identifying and locating errors.
- The programs can contain errors at many different levels. For example, errors can be:
  - **lexical**, such as misspelling an identifier, keyword, or operator
  - **syntactic**, such as an arithmetic expression with unbalanced parentheses
  - **semantic**, such as an operator applied to an incompatible operand
  - **logical**, such as an infinitely recursive call
- Often ***much of the error detection*** and recovery in a compiler is centered around the syntax analysis phase.
- One reason for this is that ***many errors are syntactic in nature*** or are exposed when the stream of tokens coming from the lexical analyzer disobeys the grammatical rules.

Context-free Grammars

A context free grammar (grammar for short) consists of terminals, non-terminals, a start symbol, and productions.

- Terminals are the basic symbols from which strings are formed. The word "**token**" is a synonym for "**terminal**" when we are talking about grammars for programming languages. Each of the keywords **if**, **then** and **else** is a terminal.
- **Non-terminals** are syntactic variables that denote sets of strings. The non-terminals define sets of strings that help to define the language generated by the grammar.
- In a grammar, one non-terminal is distinguished as the **start symbol**. And the set of strings it denotes is the language defined by the grammar.
- The **productions** of a grammar specify the manner in which the terminals and non-terminals can be combined to form strings. Each production consists of a non-terminal, followed by an arrow (sometimes the symbol := is used), followed by a string of non-terminals and terminals.

Grammar for Arithmetic Expression

expr -> expr op expr

expr -> (expr)

expr -> - expr

expr-> id

op -> +

op -> -

op -> *

op -> /

In this grammar, the terminal symbols are **id + - / ( )**

and the non-terminal symbols are **expr** and **op**.

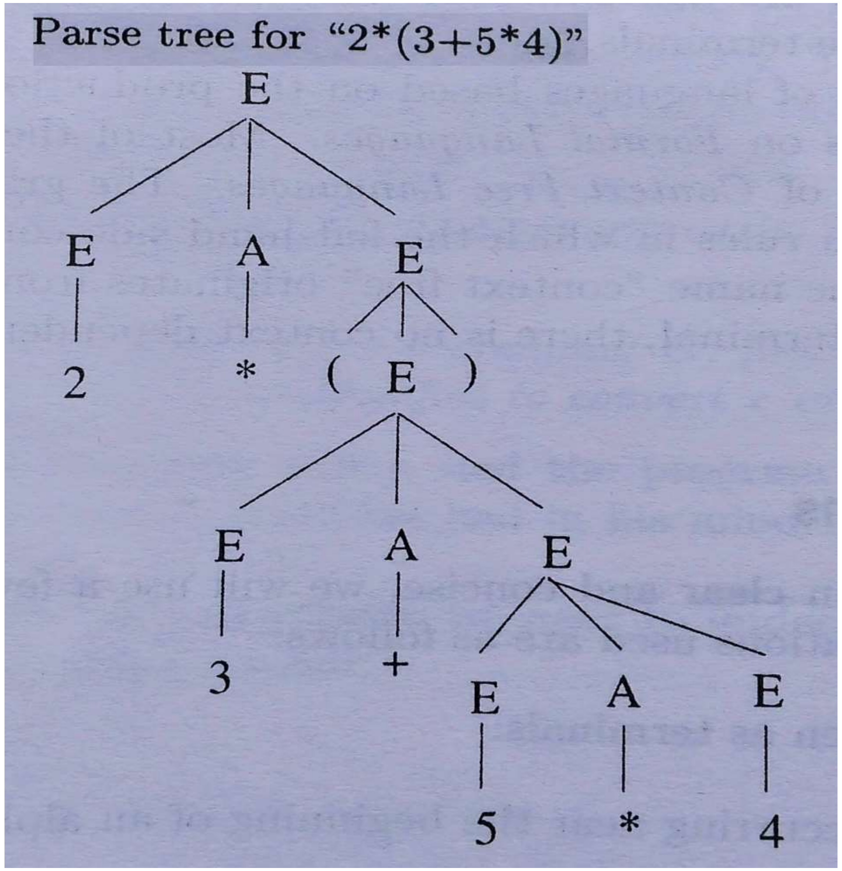
expr is the start symbol.

Derivation Tree/ Parse Tree

- The sequence of intermediary strings generated to expand the start symbol of the grammar to a desired string of terminals is called a **derivation**.
- The derivation can be represented by a tree is called **parse tree**.

E -> E A E | (E) | - E | id

A -> + | - | * | /



Derivation for "2*(3+5*4)"

E -> EAE -> 2AE -> 2*E

-> 2*(E) -> 2*(EAE)

-> 2*(3AE) -> 2*(3+E)

-> 2*(3+EAE)-> 2*(3+5AE)

-> 2*(3+5*E) -> 2*(3+5*4)

Leftmost and Rightmost Derivations

- The derivation in which the leftmost nonterminal is always replaced at each step is called ***leftmost derivation***.
- The derivation in which the rightmost nonterminal is always replaced at each step is called ***rightmost derivation***.
- In leftmost derivation, the intermediate strings are called ***left sentential forms***.
- In rightmost derivation, the intermediate strings are called ***right sentential forms***.
- The rightmost derivation is also called ***canonical representation***.

For example

expr -> expr op expr

expr -> (expr)

Leftmost derivation

expr -> expr op expr

-> (expr) op expr

Rightmost derivation

expr -> expr op expr

-> expr op (expr)

Ambiguous Grammar

- A grammar is said to be ambiguous if there exists more than one parse tree for the same sentence.
- An ambiguous grammar can have more than one leftmost and rightmost derivations.

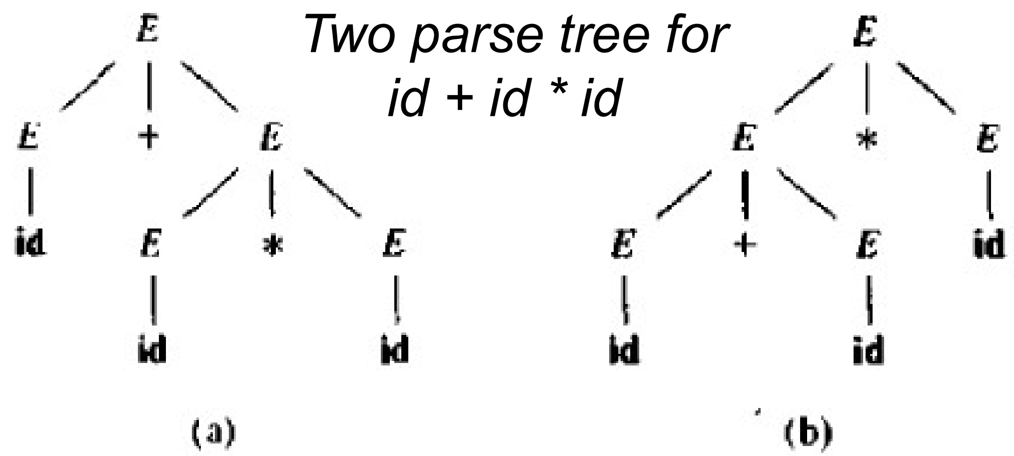
E -> E + E | E - E | E * E | E / E | (E) | - E | id

The sentence **id + id * id** has the two distinct leftmost derivations.

$$
\begin{aligned}
E &\Rightarrow E+E\\
&\Rightarrow \mathbf{id}+E\\
&\Rightarrow \mathbf{id}+E*E\\
&\Rightarrow \mathbf{id}+\mathbf{id}*E\\
&\Rightarrow \mathbf{id}+\mathbf{id}*\mathbf{id}
\end{aligned}
\qquad\qquad
\begin{aligned}
E &\Rightarrow E*E\\
&\Rightarrow E+E*E\\
&\Rightarrow \mathbf{id}+E*E\\
&\Rightarrow \mathbf{id}+\mathbf{id}*E\\
&\Rightarrow \mathbf{id}+\mathbf{id}*\mathbf{id}
\end{aligned}
$$

Operator * having higher precedence than +.

Expression a+b*c should be considered as a+(b*c) rather than as (a+b)*c.



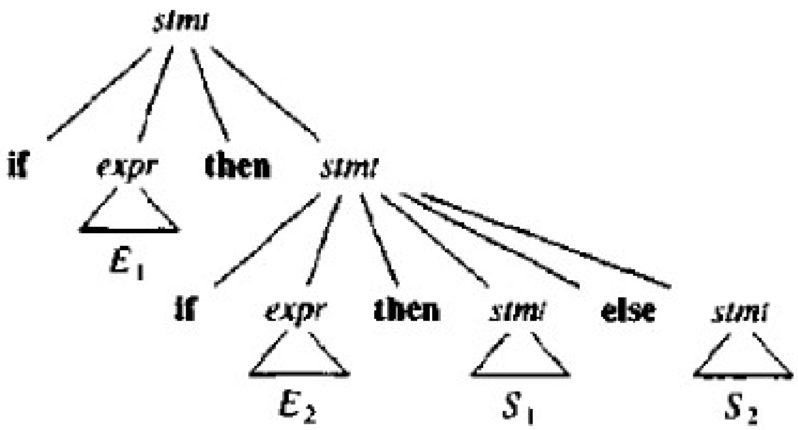
*Two parse tree for id + id * id*

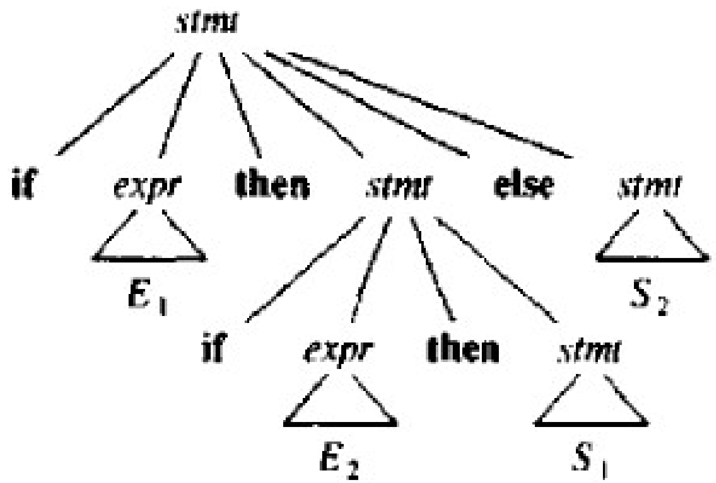
Ambiguous Grammar

stmt -> **if** expr **then** *stmt* | **if** expr **then** *stmt* **else** *stmt* | **other**

Here "other" stands for any other statement.

For example: **if** E_1 **then** **if** E_2 **then** S_1 **else** S_2






```
if  E1  then
        if  E2  then
            S1
        else
            S2
```

```
if  E1  then
    if  E2  then
        S1
else
    S2
```

Eliminating Ambiguity

- In all programming languages with conditional statements of this form, the first parse tree is preferred.
- The general rule is "Match each else with the closest previous unmatched then.
- So, we can rewrite the grammar to eliminate ambiguity.

stmt -> *matched_stmt* | *unmatched_stmt*

matched_stmt -> **if** *expr* **then** matched_*stmt*
else matched_*stmt* | **other**

unmatched_stmt -> **if** *expr* **then** *stmt* |
if expr **then** *matched_stmt* **else** *unmatched_stmt*

For example: **if** E_1 **then** **if** E_2 **then** S_1 **else** S_2

stmt -> *unmatched_stmt* -> **if** *expr* **then** *stmt* -> **if** E_1 **then** *stmt*

-> **if** E_1 **then** *matched_stmt*

-> **if** E_1 **then** **if** *expr* **then** matched_*stmt* **else** matched_*stmt*

-> **if** E_1 **then** **if** E_2 **then** S_1 **else** S_2

Eliminating Ambiguity

- To resolve the ambiguity we can add a matching ***endif*** with an if statement. So the grammar should be

stmt -> **if** expr **then** *stmt* **endif** |

if expr **then** *stmt* **else** *stmt* **endif** | **other**

For example: **if** E_1 **then** **if** E_2 **then** S_1 **else** S_2 **endif** **endif**

stmt-> **if** expr **then** *stmt* **endif** -> **if** E_1 **then** *stmt* **endif**

-> **if** E_1 **then if** expr **then** *stmt* **else** *stmt* **endif** **endif**

-> **if** E_1 **then if** E_2 **then** S_1 **else** S_2 **endif** **endif**

For example: **if** E_1 **then** **if** E_2 **then** S_1 **endif** **else** S_2 **endif**

stmt-> **if** expr **then** *stmt* **else** *stmt* **endif**

-> **if** E_1 **then** *stmt* **else** *stmt* **endif**

-> **if** E_1 **then if** expr **then** *stmt* **endif** **else** *stmt* **endif**

-> **if** E_1 **then if** E_2 **then** S_1 **endif** **else** S_2 **endif**

Left Recursion

- A grammar is left recursive if it has a nonterminal *A* such that there is a derivation *A -> Aα for some string α.*
- Top-down parsing methods cannot handle left-recursive grammars, *so* a transformation that eliminates left recursion is needed.

Elimination of Immediate Left Recursion

- The left-recursive pair of productions **A -> Aα | β** could be replaced by the non-left-recursive productions as follows:

$$A \rightarrow \beta A'$$

$$A' \rightarrow \alpha A' \mid \epsilon$$

Thus, the rule $A \rightarrow A\alpha_1 \mid A\alpha_2 \mid \dots \mid A\alpha_m \mid \beta_1 \mid \beta_2 \mid \dots \mid \beta_n$ can be modified as,

$$A \rightarrow \beta_1 A' \mid \beta_2 A' \mid \dots \mid \beta_n A'$$

$$A' \rightarrow \alpha_1 A' \mid \alpha_2 A' \mid \dots \mid \alpha_m A' \mid \epsilon$$

Elimination of Left Recursion

Eliminate Immediate Left Recursion from the following grammar:

E -> E + T | T

T -> T * F | F

F -> (E) | id

Solution:

E -> T E '

E ' -> + T E ' | ϵ

T -> F T '

T ' -> * F T ' | ϵ

F -> (E) | id

Elimination of Left Recursion

For example, consider the grammar, **S-> Aa, A->Sb | c**

Here, S is left recursive, because S-> Aa -> Sba. This form of general recursion can be eliminated with the following algorithm.

Algorithm for elimination of left recursion

1. Arrange non terminals in some order, say $A_1, A_2, \ldots, A_m$.

2. For i = 1 to m do

For j =1 to i-1 do

For each set of productions $A_i \to A_j\gamma$ and $A_j \to \delta_1 \mid \delta_2 \mid \ldots \mid \delta_k$

Replace $A_i \to A_j\gamma$ by $A_i \to \delta_1\gamma \mid \delta_2\gamma \mid \ldots \mid \delta_k\gamma$

3. Eliminate immediate left recursion from all productions

So, for the grammar **S-> Aa, A->Sb | c**

Step 1: Order of non-terminals are S, A.

Step 2: For i=1, S->Aa (there is no immediate left recursion)

For i=2, A->Sb | c is modified as, A->Aab|c

Step 3: Finally, S-> Aa, A->cA', A'->abA' | ϵ

Elimination of Left Recursion

Assignment No. 3: Eliminate Left Recursion of the following grammars.

a) A -> Ac | Aad | bd | ϵ

b) E -> E + E | E * E | (E) | id

Left Factoring

- ***Left factoring*** is a grammar transformation that is useful for producing a grammar suitable for ***predictive parsing***.
- The basic idea is that when it is not clear which of two alternative productions to use to expand a nonterminal *A,* we may be able to rewrite the A-productions to defer the decision until we have seen enough of the input to make the right choice.
- For example, if we have the two productions

  stmt -> **if** expr **then** *stmt* **else** *stmt* | **if** expr **then** *stmt*

- On seeing the input token **if**, we cannot immediately tell which production to choose to expand *stmt*. Only after **then**, if token **else** is found, we can decide the first rule to be used.
- This necessitates backtracking if token **else** is absent in the input stream, that is, it is an if-then statement. To **eliminate** this problem, the grammar is **left-factored** to take out the common portion separately as follows:

  stmt -> **if** expr **then** *stmt* *else-clause*

  else_clause **->** ***else*** *stmt* **| ϵ**

Algorithm for Left Factoring

- *Input:* Grammar G.
- Output: An equivalent left-factored grammar.
- Method: For each nonterminal *A* find the longest prefix α common to two or more of its alternatives. If $\alpha \neq \epsilon$, i.e., there is a nontrivial common prefix, replace all the A productions **$A \rightarrow \alpha\beta_1 \mid \alpha\beta_2 \mid \ldots \mid \alpha\beta_n \mid \gamma$** where γ represents all alternatives that do not begin with **α** by

  $A \rightarrow \alpha A' \mid \gamma$

  $A' \rightarrow \beta_1 \mid \beta_2 \mid \ldots \mid \beta_n$

Here A' is a new nonterminal. Repeatedly apply this transformation until no two alternatives for a nonterminal have a common prefix.

For example: ***S->iEtS | iEtSeS | a***

E->b

After Left Factoring:

S->iEtSS' | a

S'->eS | ϵ

E->b

Top-Down Parsing

- Top-down parsers get the name from the fact that they try to find a derivation of the input stream from the start symbol of the grammar.
- Equivalently, it can be viewed as an attempt to construct the parse tree rooted at the start symbol of the grammar for the input stream. There are two main approaches for top-down parsing.
  - **Recursive descent parsing**
  - **Predictive parsing**

Recursive Descent Parsing

- Top-down parsing can be viewed as an attempt to find a leftmost derivation for an input string.
- 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.
- A general form of top-down parsing, called recursive descent, that may involve backtracking, that is, making repeated scans of the input.
- However, backtracking parsers are not seen frequently due to inefficiency.

Recursive Descent Parsing

Example: Consider the grammar

S->abA,   A->cd | c | ϵ

For the input stream **ab**:

- The parser starts by constructing a parse tree representing S->abA as shown in Fig. (a).
- The tree is expanded with the production A->cd as shown in Fig. (b).
- Since it does not match the string ab, the parser backtracks and then, tries the alternative A->c as shown in Fig. (c). However, the parse tree does not match the string ab.
- So, the parser backtracks and tries out the alternative A->ϵ as shown in Fig. (d). This time it finds a match. Thus, the parsing is complete and successful.

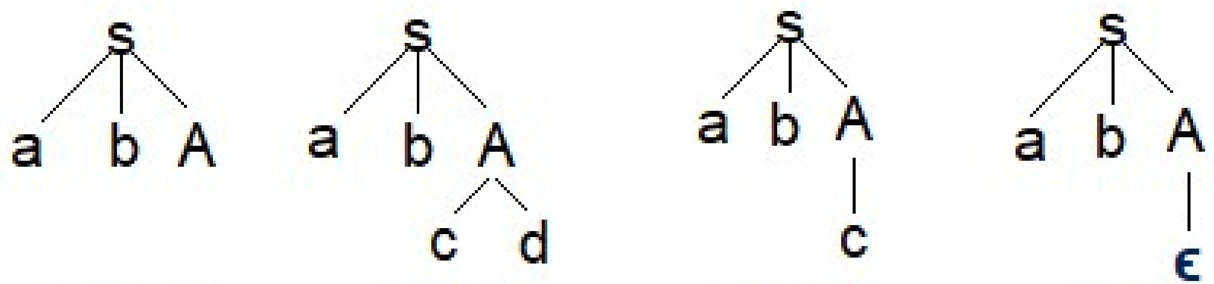


Fig. (a) Fig. (b) Fig. (c) Fig. (d)

Recursive Descent Parsing

- If the grammar is ***left-recursive***, a recursive descent parser ***may fall into an infinite loop*** even in the presence of backtracking.
- This happens because of the fact that for a left-recursive rule, the parser has to expand without consuming any further input symbol.
- A parser construction strategy, known as ***predictive parser*** is developed to create a recursive descent parser that ***does not need backtracking***.
- The ***predictive parser*** can be constructed in both ***recursive and non-recursive*** manner.

Recursive Predictive Parsing

- 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.
- To construct a predictive parser, we must know, given the current input symbol ***a*** and the nonterminal ***A*** to be expanded, which one of the alternatives of production $A \to \alpha_1 \mid \alpha_2 \mid \ldots \mid \alpha_n$ is the unique alternative that derives a string beginning with ***a****.* That is, the proper alternative must be detectable by looking at only the first symbol it derives.
- Flow-of-control constructs in most programming languages, with their distinguishing keywords are usually detectable in this way.
- For example, if we have the productions

  stmt -> **if** expr **then** *stmt* **else** *stmt* | **while** *expr* ***do*** *stmt*

  then the keywords **if** and **while** tell us which alternative is the only one that could possibly succeed if we are to find a statement.

Recursive Predictive Parsing

- **After left factoring**, the resultant rules can also be represented in the form of a set of transition diagrams. For this purpose we can **create a diagram for each nonterminal** *A*.
  1. Create an initial and final (return) state.
  2. For each production A -> X_1 X_2 … X_n, create a path from the initial state to the final state, with edge labeled X_1 ,X_2, … ,X_n.
- The predictive parser begins in the start state **s** for the start symbol. If after some actions it moves to a state **t** with an edge label of terminal **a**, and if the next input symbol is **a**, then the parser moves the input cursor one position right and goes to state **t**.
- If 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 **ϵ**, then from state **s** the parser immediately goes to state **t**, without advancing the input.

Recursive Predictive Parsing

For example: exp -> exp + term | term

term -> term * factor | factor

factor -> (exp) | **id**

After removal of left-recursion we get

exp -> term exp_tail

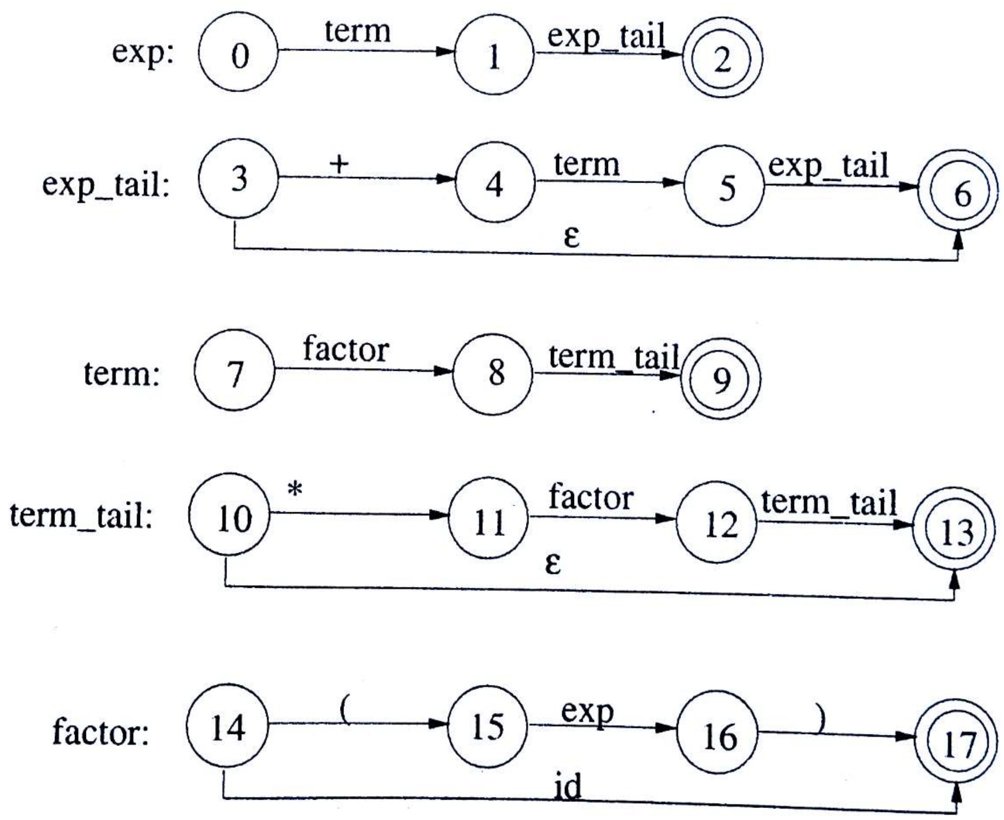
exp_tail -> + term expr_tail | ϵ

term -> factor term_tail

term_tail -> * factor term_tail | ϵ

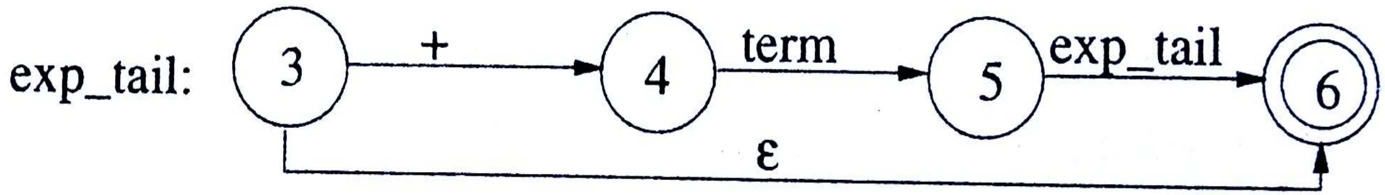
factor -> (exp) | **id**

Transition Diagrams

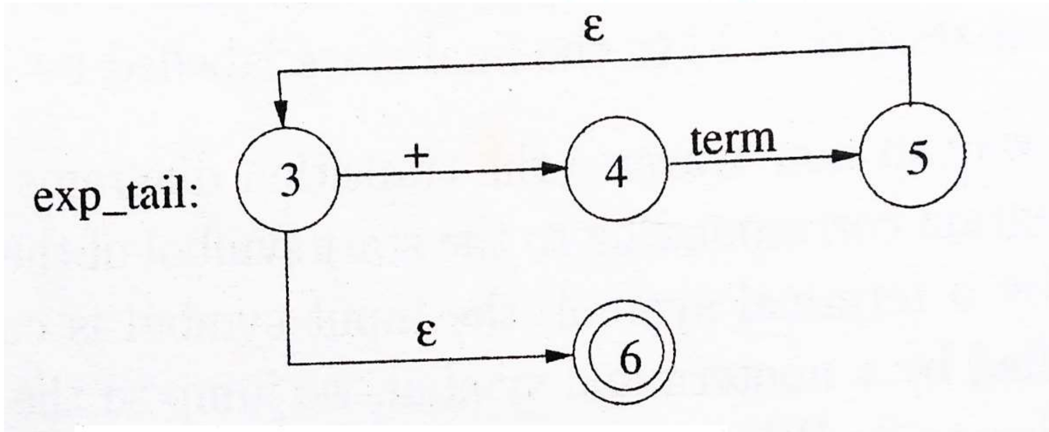


Recursive Predictive Parsing

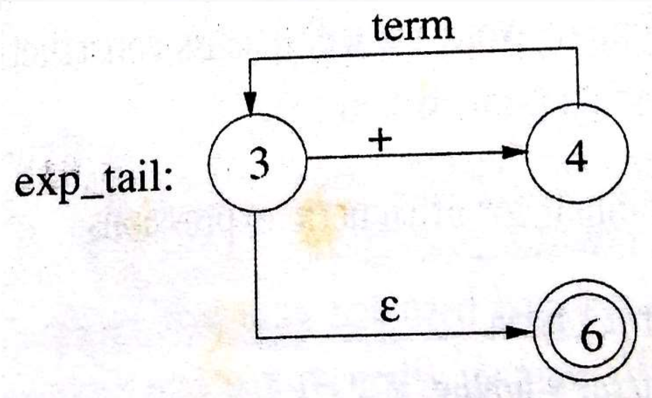
Simplification of diagrams may create a more compact and efficient parser.



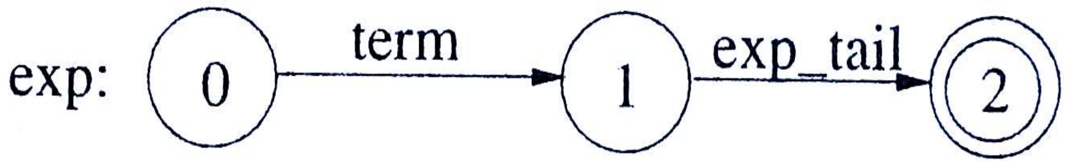
First, we eliminate self-recursion in the exp_tail transition diagram, substituting an iterative model.



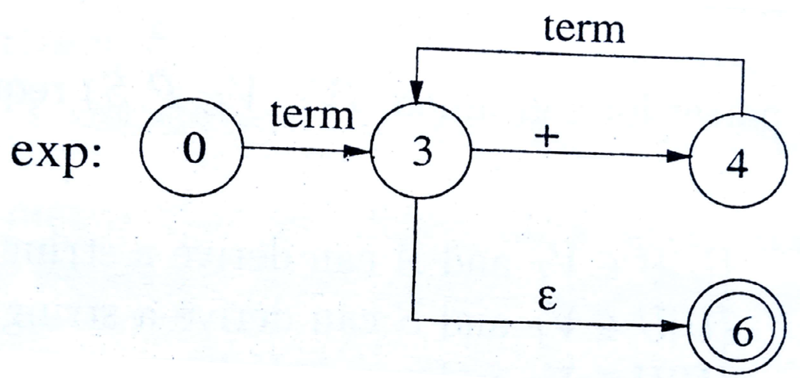
Further simplification by removing the redundant ϵ-edge.



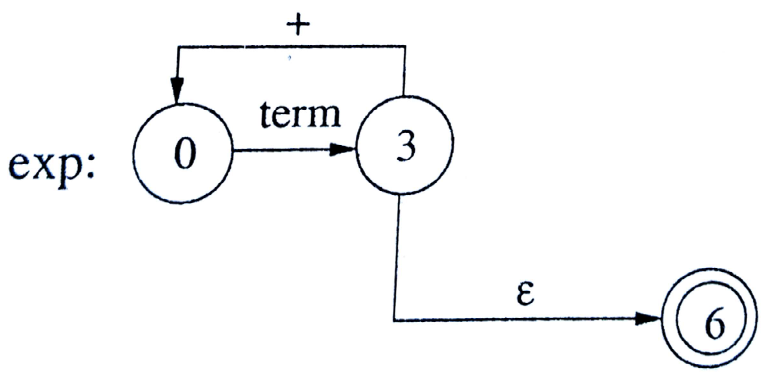
Recursive Predictive Parsing



If we substitute the exp_tail diagram in the exp one, replacing the exp_tail edge from 1 to 2, we get



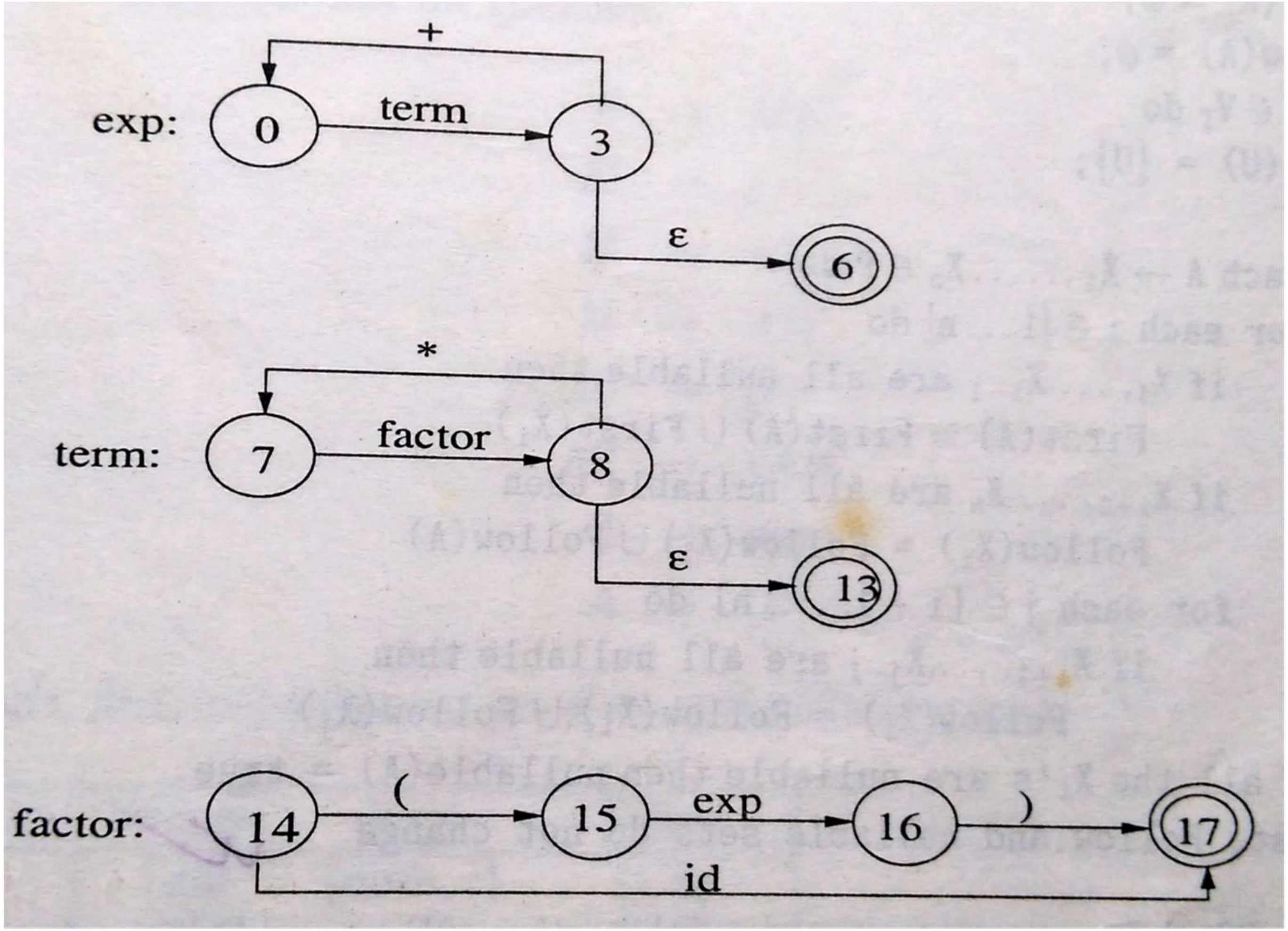
By further simplification we get



Recursive Predictive Parsing

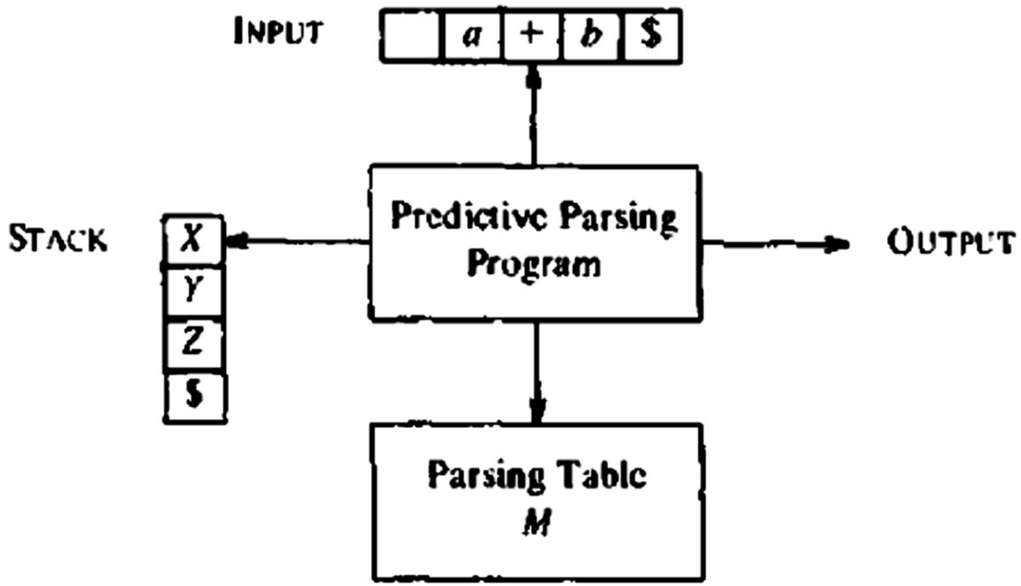
Applying the same approach to term and term_tail, we get a reduced set of diagrams for arithmetic expressions as shown below.

Final Set of Transition diagrams for expression grammar



Non-Recursive Predictive Parsing- LL(k) Parsing

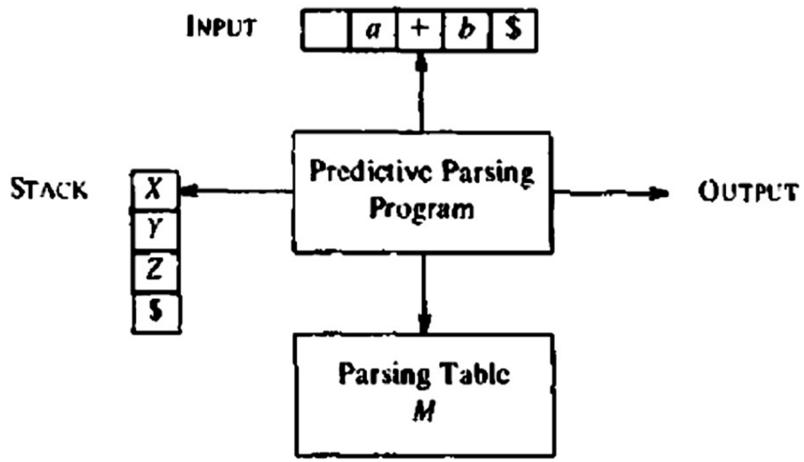
- It is possible to build a nonrecursive predictive parser by maintaining a stack explicitly, rather than implicitly via recursive calls. The key problem during predictive parsing is that of determining the production to be applied for a nonterminal. The nonrecursive parser looks up the production to be applied in a parsing table.



- This parser scan over the input stream using a prefix of tokens to identify the production applied. This parser is also called LL(k) parser, where k is the length of the prefix. “LL” stands for left-to-right scanning of the input stream and left-most derivation respectively.

Non-Recursive Predictive Parsing- LL(k) Parsing

- A table-driven predictive parser has an input buffer, a stack, a parsing table, and an output stream.
- 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.
- 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 $.
- The parsing table is a two dimensional array M[A, a], where A is a nonterminal, and a is a terminal or the symbol $.



Non-Recursive Predictive Parsing- LL(k) Parsing

Why FIRST and FOLLOW in Compiler Design?

- The need of backtracking is really a complex process to implement a parser.
- If the compiler would have come to know in advance, that what is the "**first** character of the string produced when a production rule is applied", and comparing it to the current character or token in the input string, it can wisely take decision on which production rule to apply.

  S -> cAd

  A -> bc|a

  And the input string is "cad".
- After reading character 'c' in the input string and applying S->cAd, next character in the input string is 'a', then it would directly use the production rule A->a.

Non-Recursive Predictive Parsing- LL(k) Parsing

Why FIRST and FOLLOW in Compiler Design?

- The parser faces one more problem. Let us consider below grammar to understand this problem.

  A -> aBb

  B -> c | ε

  And suppose the input string is "ab" to parse.

- As the first character in the input is a, the parser applies the rule A->aBb. Now the parser checks for the second character of the input string which is b, and the Non-Terminal to derive is B, but the parser can't get any string derivable from B that contains b as first character.
- But the Grammar does contain a production rule B -> ε, if that is applied then B will vanish. But the parser can apply it only when it knows that the character that follows B in the production rule is same as the current character in the input.

Non-Recursive Predictive Parsing- LL(k) Parsing

Rules to Calculate First(X)

To compute First(X) for all grammar symbols X, apply the following rules:

1. If X is a terminal, then First(X) is {X}.
2. If X->ϵ is a production, then add ϵ to First(X).
3. If X is nonterminal and X->Y_1 Y_2 … Y_k is a production, then place a in First(X) if for some i, a is in First(Y_i), and ϵ is in all of First(Y_1), . . . First(Y_{i-1}); that is, $Y_1 \dots Y_{i-1} \approx \epsilon$. If ϵ is in First($Y_j$) for all *j* = 1, 2, . . . , k, then add ϵ to First(X).

Non-Recursive Predictive Parsing- LL(k) Parsing

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Example:

E -> T E '

E ' -> + T E ' | ϵ

T -> F T '

T ' -> * F T ' | ϵ

F -> (E) | id

First(F)={First((E)), First(id))

First(T')={First(* FT '), ϵ)}

First(T)={First(F)}

First(E')={First(+TE '), ϵ)}

First(E)={First(T)}

	First
E	{(,id}
E’	{+,ε}
T	{(,id}
T’	{*,ε}
F	{(,id}

Non-Recursive Predictive Parsing- LL(k) Parsing

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Consider the grammar

S -> aABe   A -> Abc | b   B -> d

Show the First sets for each nonterminal symbol.

First(B) = {First(d)} = {d}

First(A) = {First(Abc), First(b)} = {First(A), b} ={b}

First(S) = {First(aABe)}={a}

	First
S	**{a}**
A	**{b}**
B	**{d}**

Non-Recursive Predictive Parsing- LL(k) Parsing

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To compute First(X) for all grammar symbols X, apply the following rules:

1. If X is a terminal, then First(X) is {X}.
2. If X->ϵ is a production, then add ϵ to First(X).
3. If X is nonterminal and X->Y_1 Y_2 … Y_k is a production, then place a in First(X) if for some i, a is in First(Y_i), and ϵ is in all of First(Y_1), . . . First(Y_{i-1}); that is, $Y_1 \ldots Y_{i-1} \approx \epsilon$. If ϵ is in First($Y_j$) for all *j* = 1, 2, . . . , k, then add ϵ to First(X).

Consider the grammar

S -> A | B,   A -> cA+b | a, B -> cB + a | b

Show the First sets for each nonterminal symbol.

First(B)={c, b}

First(A)={c, a}

First(S) ={First(A), First(B)} = {a, b, c}

	First
S	{a,b,c}
A	{a, c}
B	{b, c}

Non-Recursive Predictive Parsing- LL(k) Parsing

Rules to Calculate First(X)

To compute First(X) for all grammar symbols X, apply the following rules:

1. If X is a terminal, then First(X) is {X}.
2. If X->ϵ is a production, then add ϵ to First(X).
3. If X is nonterminal and $X \to Y_1\ Y_2 \ldots Y_k$ is a production, then place a in First(X) if for some i, a is in First(Y_i), and ϵ is in all of First(Y_1), . . . First(Y_{i-1}); that is, $Y_1 \ldots Y_{i-1} \approx \epsilon$. If ϵ is in First($Y_j$) for all *j* = 1, 2, . . . , k, then add ϵ to First(X).

Consider the grammar

$$\begin{aligned} S &\to iEtSS' \mid a \\ S' &\to eS \mid \epsilon \\ E &\to b \end{aligned}$$

Show the First sets for each nonterminal symbol.

	First
S	{i, a}
S'	{e, ε}
E	{b}

Non-Recursive Predictive Parsing- LL(k) Parsing

Rules to Calculate Follow(A)

To compute Follow(X) for all grammar symbols X, apply the following rules:

1. Place $ in Follow(S), where S is the start symbol and $ is the input right endmarker.
2. If there is a production, $A \rightarrow \alpha B \beta$, then everything in First(β) except for ϵ is placed in Follow(B).
3. If there is a production, $A \rightarrow \alpha B$, or a production $A \rightarrow \alpha B \beta$ where First(β) contains ϵ (i.e. $\beta \approx \epsilon$), then everything in Follow(A) is in Follow(B).

Non-Recursive Predictive Parsing- LL(k) Parsing

Rules to Calculate Follow(A)

To compute Follow(X) for all grammar symbols X, apply the following rules:

1. Place \$ in Follow(S), where S is the start symbol and \$ is the input right endmarker.
2. If there is a production, A->αBβ, then everything in First(β) except for ϵ is placed in Follow(B).
3. If there is a production, A-> αB, or a production A->αBβ where First(β) contains ϵ (i.e. β ≈ ϵ), then everything in Follow(A) is in Follow(B).

Example:

E -> T E '

E ' -> + T E ' | ϵ

T -> F T '

T ' -> * F T ' | ϵ

F -> (E) | id

Follow(E)={\$, First( ))}

Follow(E')={Follow(E)}

Follow(T)={First(E '), Follow(E)}

Follow(T')={Follow(T)}

Follow(F)={First(T '), Follow(T))

	First	Follow
E	{(,id}	{), \$}
E’	{+,ε}	{), \$}
T	{(,id}	{+,), \$}
T’	{*,ε}	{+,), \$}
F	{(,id}	{+, *,), \$}

Non-Recursive Predictive Parsing- LL(k) Parsing

Rules to Calculate Follow(A)

To compute Follow(X) for all grammar symbols X, apply the following rules:

1. Place $ in Follow(S), where S is the start symbol and $ is the input right endmarker.
2. If there is a production, A->αBβ, then everything in First(β) except for ϵ is placed in Follow(B).
3. If there is a production, A-> αB, or a production A->αBβ where First(β) contains ϵ (i.e. β ≈ ϵ), then everything in Follow(A) is in Follow(B).

Consider the grammar S -> aABe A -> Abc | b B -> d

Show the First and Follow sets for each nonterminal symbol.

Follow(S) = {$}

Follow(A) = {First(B), First(b)}={d, b}

Follow(B) = {First(e)} ={ e }

	First	Follow
S	{a}	{$}
A	{b}	{b, d}
B	{d}	{e}

Non-Recursive Predictive Parsing- LL(k) Parsing

Rules to Calculate Follow(A)

To compute Follow(X) for all grammar symbols X, apply the following rules:

1. Place \$ in Follow(S), where S is the start symbol and \$ is the input right endmarker.
2. If there is a production, $A \to \alpha B \beta$, then everything in First(β) except for ϵ is placed in Follow(B).
3. If there is a production, $A \to \alpha B$, or a production $A \to \alpha B \beta$ where First(β) contains ϵ (i.e. $\beta \approx \epsilon$), then everything in Follow(A) is in Follow(B).

Consider the grammar S -> A | B, A -> cA+b | a, B -> cB + a | b

Show the First and Follow sets for each nonterminal symbol.

First(B)={c, b}

First(A)={c, a}

First(S) ={First(A), First(B)} = {a, b, c}

Follow(S)={\$}

Follow(A)={Follow(S), +}

Follow(B)={Follow(S), +}

	First	Follow
S	{a,b,c}	{\$}
A	{a, c}	{+, \$}
B	{b, c}	{+, \$}

Non-Recursive Predictive Parsing- LL(k) Parsing

LL(1) Grammar

A grammar is an LL(1) if all productions conform to the following LL(1) conditions:

1. For each production $A \rightarrow \alpha_1 | \alpha_2 | \ldots | \alpha_n$, $First(\alpha_i) \cap First(\alpha_j) = \Phi, \forall i \neq j$
2. If nonterminal X can derive ϵ, then $First(X) \cap Follow(X) = \Phi$

Check the grammar S -> A | B, A -> cA+b | a, B -> cB + a | b is LL(1) or not.

First(B)={c, b}

First(A)={c, a}

First(S) ={First(A), First(B)} = {a, b, c}

Follow(S)={$}

Follow(A)={Follow(S), +}

Follow(B)={Follow(S), +}

	First	Follow
S	{a, b, c}	{$}
A	{a, c}	{+, $}
B	{b, c}	{+, $}

First(A) ∩ First(B) = {c}
So, this is not LL(1).

Non-Recursive Predictive Parsing- LL(k) Parsing

Assignment No. 04

Consider the grammar

A -> BCx | y

B -> yA | ϵ

C -> Ay | x

Where {A, B, C} is the set of nonterminal symbols, A is the start symbol, (x, y) is the set of terminal symbols.

1. Show the First and Follow sets for each nonterminal symbol.
2. Check the grammar is in LL(1) or not.

Non-Recursive Predictive Parsing- LL(k) Parsing

Construction of Predictive Parsing Table

1. **For each production A -> α of the grammar**
   - **For each terminal a in First(α), add A -> α to M[A, a].**
   - **If ϵ is in First(α), add *A->α* to M[A, b]** for **each terminal *b* in Follow(A).**
   - **If ϵ is in First(α) and $ is in Follow(A), add *A->α* to M[A, $].**
2. **Make each** undefined **entry of *M*** be **error.**

	First	Follow
E	{(,id}	{), $}
E'	{+,ε}	{), $}
T	{(,id}	{+,), $}
T'	{*,ε}	{+,), $}
F	{(,id}	{+, *,), $}

E -> T E'   **E ' -> + T E ' | ϵ**   **T -> F T '**   **T ' -> * F T ' | ϵ**   **F -> (E) | id**

NONTER-MINAL	INPUT SYMBOL					
	id	+	*	(	)	$
E	$E \to TE'$			$E \to TE'$		
E'		$E' \to +TE'$			$E' \to \epsilon$	$E' \to \epsilon$
T	$T \to FT'$			$T \to FT'$		
T'		$T' \to \epsilon$	$T' \to *FT'$		$T' \to \epsilon$	$T' \to \epsilon$
F	$F \to \text{id}$			$F \to (E)$		

Non-Recursive Predictive Parsing- LL(k) Parsing

Construction of Predictive Table

$$S \rightarrow iEtSS' \mid a$$
$$S' \rightarrow eS \mid \epsilon$$
$$E \rightarrow b$$

Follow(S)={$, First(S'), Follow(S')}

Follow(S')={Follow(S)}

Follow(E)={t}

	First	Follow
S	{i, a}	{$, e}
S'	{e, ε}	{$, e}
E	{b}	{t}

NONTERMINAL	INPUT SYMBOL					
	a	b	e	i	t	$\$$
S	$S \rightarrow a$			$S \rightarrow iEtSS'$		
S'			$S' \rightarrow \epsilon$ $S' \rightarrow eS$			$S' \rightarrow \epsilon$
E		$E \rightarrow b$				

Non-Recursive Predictive Parsing- LL(k) Parsing

Nonrecursive predictive parsing

Set *ip* to point to the first symbol of ***w$***

Repeat

Let X be the top stack symbol and ***a*** the symbol pointed to by *ip*

If X is a terminal or ***$*** **Then**

If X = ***a*** **Then**

pop X from the stack and advance *ip*

Else parsing error

Elseif M[X, ***a***] = $X \text{->} Y_1 Y_2 \ldots Y_k$ **Then** /* X is a nonterminal */

pop X from the stack and

push Y_k, $Y_{k-1}, \ldots,$ Y_1 onto the stack, with Y_1 on top;

output the production $X \text{->} Y_1, Y_2 \ldots Y_k$

Else parsing error

Until X = ***$*** /* stack is empty */

Non-Recursive Predictive Parsing- LL(k) Parsing

NONTERMINAL	INPUT SYMBOL id	+	*	(	)	$
E	$E \to TE'$			$E \to TE'$		
E'		$E' \to +TE'$			$E' \to \epsilon$	$E' \to \epsilon$
T	$T \to FT'$			$T \to FT'$		
T'		$T' \to \epsilon$	$T' \to *FT'$		$T' \to \epsilon$	$T' \to \epsilon$
F	$F \to \mathrm{id}$			$F \to (E)$		

id + id * id

Set *ip* to point to the first symbol of ***w$***

Repeat

Let X = top stack symbol and ***a*** is pointed by *ip*

If X is a terminal or $\$$ **Then**

If $X = a$ **Then**

pop X from the stack and advance *ip*

Else parsing error

Elseif M[X, *a*] = $X \text{->} Y_1 Y_2 \ldots Y_k$ **Then**

pop X from the stack and

push $Y_k, Y_{k-1}, \ldots, Y_1$ onto the stack Y_1 on top;

output the production $X \text{->} Y_1\ Y_2 \ldots Y_k$

Else parsing error

Until $X = \$$ /* stack is empty */

STACK	INPUT	OUTPUT
$E	id + id * id$	
$E'T	id + id * id$	$E \to TE'$
$E'T'F	id + id * id$	$T \to FT'$
$E'T'id	id + id * id$	$F \to \mathrm{id}$
$E'T'	+ id * id$	
$E'	+ id * id$	$T' \to \epsilon$
$E'T +	+ id * id$	$E' \to +TE'$
$E'T	id * id$	
$E'T'F	id * id$	$T \to FT'$
$E'T'id	id * id$	$F \to \mathrm{id}$
$E'T'	* id$	
$E'T'F*	* id$	$T' \to *FT'$
$E'T'F	id$	
$E'T'id	id$	$F \to \mathrm{id}$
$E'T'	$	
$E'	$	$T' \to \epsilon$
$	$	$E' \to \epsilon$

THANK YOU