Note Junction

Best Note Provider

Note By: Roshan BiSt

UNIT-1

Introduction to Compiler

A compiler is a translator software program that takes its input in the form of program written in one particular programming language and produce the output in the form of program in another language.

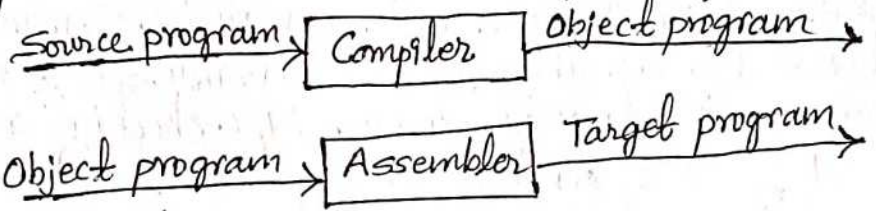
Features of Compiler:

→ A compiler is a translator the converts the high-level language into the machine language.

→ High-level language is written by a developer and machine language can be understood by the processor.

→ Compiler is used to show errors to the programmer.

→ Compiler executes a program into two parts: In first, source program is compiled into object program, In second, object program is translated into target program.



⊛Compiler Structure:

A compiler operates in phases. A phase is a logically interrelated operation that takes source program in one representation and produces output in another representation. There are two phases of compilation:

1) Analysis phase: In analysis part, an intermediate representation is created from the given source program. This part is called front end of the compiler. This part consists of mainly four phases:

i) Lexical Analysis: Lexical analysis or scanning is the process where the source program is read from left-to-right and grouped into tokens. Tokens are sequences of characters with a collective meaning. In any programming language tokens may be constants, operators, reserved words etc. The Lexical Analyzer takes a source program as input, and produces a stream of tokens as output.

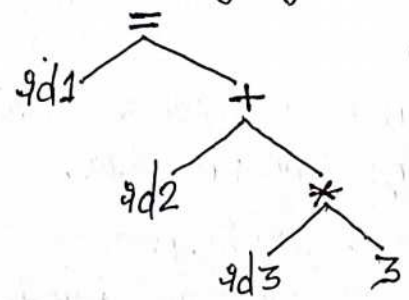
Example:

Input string: c=a+b*3

Tokens: id1 = id2 + id3 * 3

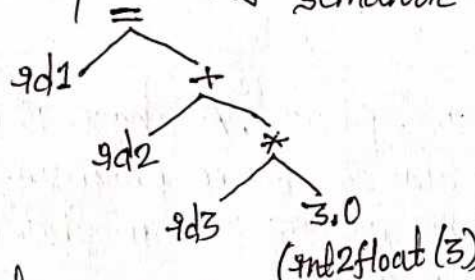
ii) Syntax Analysis: In this phase, the syntax analyzer takes the token produced by lexical analyzer as input and generates a parse tree as output. In syntax analysis phase, the parser checks that the expression made by the token is syntatically correct or not, according to the rules that define the syntax of the source language.

Example:



iii) Semantic Analysis: In this phase, the semantic analyzer checks the source program for semantic errors and collects the type information for the code generation. Semantic analyzer checks whether they form a sensible set of instructions in the programming language or not. Type-checking is an important part of semantic analyzer.

Example:



iv) Intermediate Code Generation: If the program syntatically and semantically correct then intermediate code generator generates a simple machine independent intermediate language. The intermediate code should be generated in such a way that it can easily be translated into the target machine code.

Example:

```
t1 = 3.0;
t2 = id3 * t1;
t3 = id2 + t2;
id1 = t3;
```

2) Synthesis phase: In synthesis part, the equivalent target program is created from intermediate representation of the program created by analysis part. This part is also called back end of the compiler. This part consists of mainly two phases:

i) Code Optimization: It is used to improve the intermediate code so that the output of the program could run faster and takes less space. It removes the unnecessary lines of the code and arranges the sequence of statements in order to speed up the program execution without wasting resources.

Example:
```
t2 = id3 * 3.0;
id1 = id2 + t2;
```

ii) Code Generation: Code generation is the final stage of the compilation process. It takes the optimized intermediate code as input and maps it to the target machine language.

Example:
```
MOV R1, id3
MUL R1, #3.0
MOV R2, id2
ADD R1, R2
MOV id1, R1.
```

⊛. Symbol Table: Symbol tables are data structures that are used by compilers to hold information about source-program constructs. The information is collected incrementally by the analysis phase of compiler and used by the synthesis phases to generate the target code. Entries in the symbol table contain information about an identifier such as its type, its position in storage, and any other relevant information.

⊛. Error Handling: Whenever an error is encountered during the compilation of the source program, an error handler is invoked. Error handler generates a suitable error reporting message regarding the error encountered. Errors can be encountered at any phase as:

Lexical analysis phase: due to misspelled tokens, unrecognized characters etc.
Syntax analysis phase: due to syntatic violation of language.
Intermediate code generation: due to incompatibility of operands type for operator.
Code optimization phase: due to some unreachable statements.

Block Diagram:

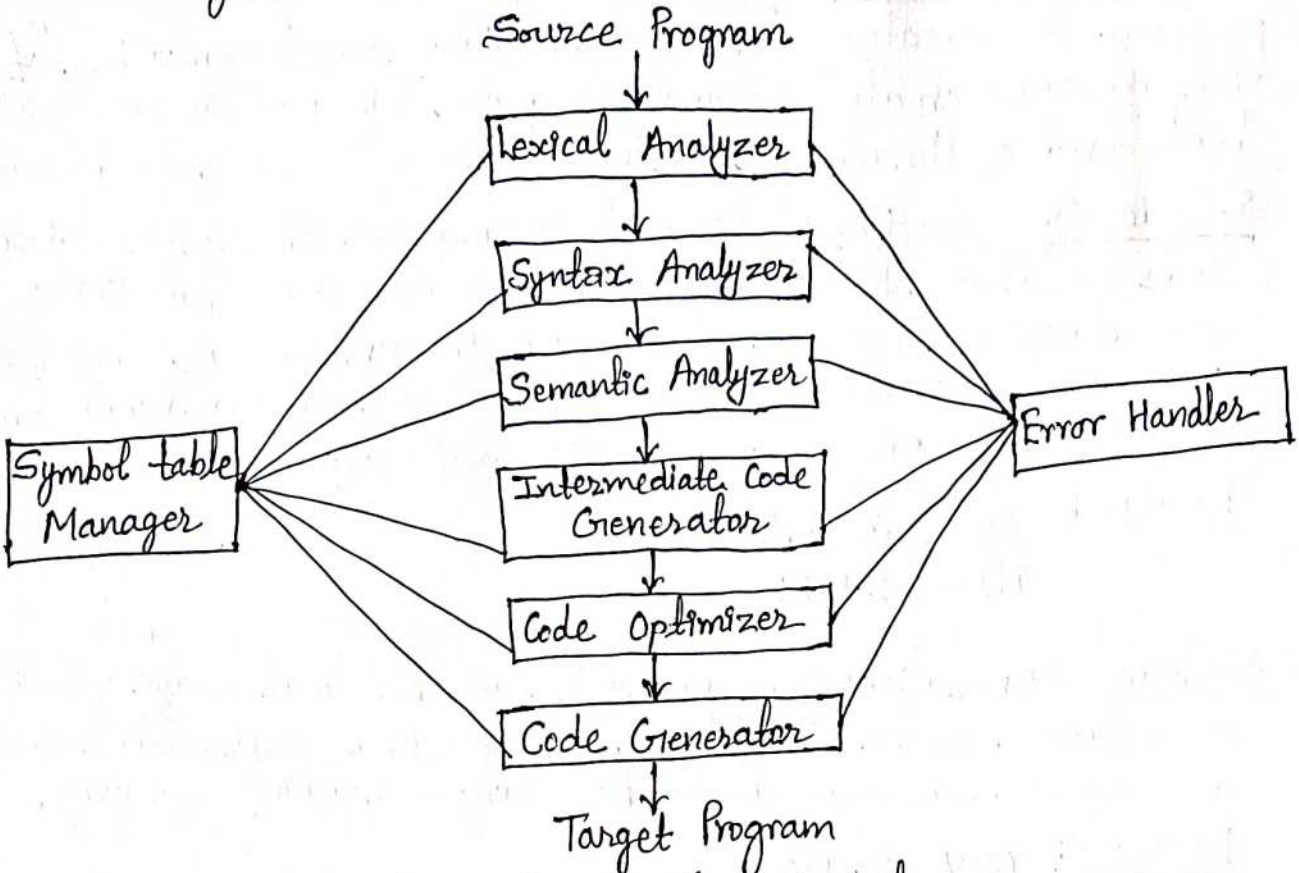


Fig: Phases of a Compiler

⊛. Compiler vs Interpreter:

Compiler	Interpreter
i) Compiler is a translator which takes input i.e, high-level language, and produces an output of low-level language.	i) An Interpreter is a program that translates a programming language into a comprehensible language.
ii) Compiler scans the whole program in one go.	ii) Interpreter translates one statement at a time.
iii) Errors are shown at the end together as it scans full code in one go.	iii) Errors are shown line by line as it scans code one line at a time.
iv) It does not require source code for later execution.	iv) It requires source code for later execution.
v) It converts source code into object code.	v) It does not convert source code into object code instead it scans it line by line.

⊛. Simple or One pass Compiler vs. Multi-pass Compiler:

(Simple) One pass compiler	Multi-pass compiler
i) In a one pass compiler all the phases are combined into one pass.	i) In multi-pass compiler different phases of compiler are grouped into multiple phases.
ii) Here intermediate representation of source program is not created.	ii) Here intermediate representation of source program is created.
iii) It is faster than multi-pass compiler.	iii) It is slightly slower than one pass compiler.
iv) It is also called narrow compiler.	iv) It is also called wide compiler.
v) Pascal's compiler is an example of one pass compiler.	v) C++ compiler is an example of multi-pass compiler.

⊛. Preprocessor: A preprocessor, generally considered as a part of compiler, is a tool that produces input for compilers. It deals with macro-processing, agumentation, file inclusion etc.

Functions:

i) Macro processing: A preprocessor may allow a user to define macros that are short hands for longer constructs.

ii) File inclusion: A preprocessor may include header files into the program text.

iii) Rational preprocessor: These preprocessors augment older languages with more modern flow-of-control and data structuring facilities.

iv) Language Extensions: These preprocessor attempts to add capabilities to the language by certain amounts to build-in macro.

⊛. Macros: A macro stands for macroinstruction is a programmable pattern which translates a certain sequence of input into a present sequence of output. Macros can make tasks less repetitive by representing a complicated sequence of keystrokes, mouse movements, commands, or other types of input.

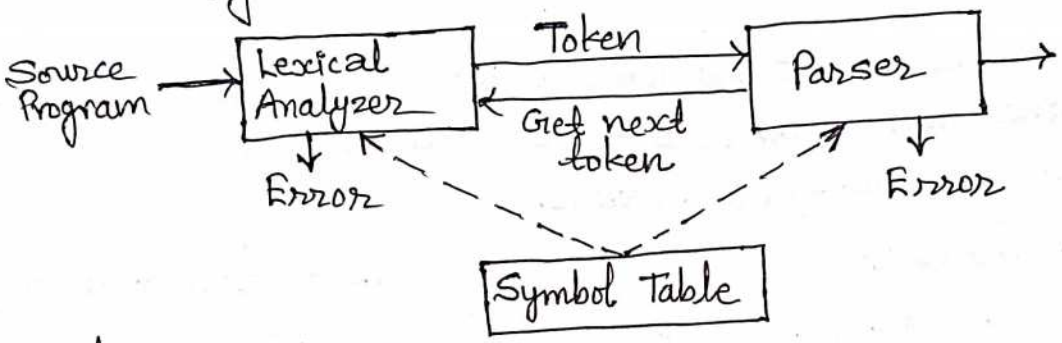
Features of macro processor:

→ It represents a group of commonly used statements in the source programming language.
→ Using macro instructions programmer can leave the mechanical details to be handled by macro processor.
→ Macro processor designs is not directly related to the computer architecture on which it runs.
→ Macro processor involves definition, invocation and expansion.

lexical analysis is done for validation of tokens

UNIT-2
Lexical Analyzer

Lexical Analysis: The lexical analysis is the first phase of a compiler where a lexical analyzer acts as an interface between the source program and the rest of the phases of compiler. It reads input characters of the source program, groups them into lexemes, and produces a sequence of tokens for each lexeme. The tokens are then sent to the parser for syntax analysis.



Example: Example of Lexical Analysis, Tokens, Non-Tokens

Consider the following code that is fed to Lexical Analyzer.

```
#include <stdio.h>
int Largest (int x, int y)
{
   if (x>y) //This will compare two numbers
      return x;
   else
      return y;
}
```

Examples of Tokens created:

Lexeme	Token
int	Keyword
largest	Identifier
(	Operator
int	Keyword
x	Identifier
,	Operator
int	Keyword
y	Identifier
)	Operator
{	Operator
if	Keyword

Examples of Non-Tokens:

Type	Examples
Comment	// This will compare 2 numbers.
Pre-processor directive	#include <stdio.h>

Role of Lexical Analyzer:

→ Lexical analyzer helps to identify token into the symbol table.
→ It can either work as a seperate module or as a sub-module.
→ It is responsible for eliminating comments and white spaces from the source program.
→ It reads the input character and produces output sequence of tokens that the Parser uses for syntax analysis.
→ It also generates lexical errors.
→ Lexical analyzer is used by web browsers to format and display a web page with the help of parsed data from Javascript, HTML, CSS.

Lexemes, Patterns, Tokens:

Lexemes: A lexeme is a sequence of alphanumeric characters that is matched against the pattern for token. A sequence of input characters that make up a single token is called a lexeme. A token can represent more than one lexeme.
Example: The token "String constant" may have a number of lexemes such as "bh", "sum", "area", "name" etc.

Patterns: Patterns are the rules for describing whether a given lexeme belonging to a token or not. The rule associated with each set of string is called pattern. Lexeme is matched against pattern to generate token. Regular expressions are widely used to specify patterns.

Token: Token is word, which describes the lexeme in source program. It is generated when lexeme is matched against pattern. A token is a logical building block of language. They are the sequence of characters having a collective meaning.

Example1: Example showing lexeme, token and pattern for variables.

- Lexeme: A1, Sum, Total
- Pattern: Starting with a letter and followed by letter or digit but not a keyword.
- Token: ID

Example2: Example showing lexeme, token and pattern for floating number.

- Lexeme: 123.45
- Pattern: Starting with digit followed by a digit or optional fraction and or optional exponent.
- Token: NUM

⊛Specifications of Tokens:

Regular Expression is a way to specify tokens. The regular expression represents the regular languages. The language is the set of strings and string is the set of alphabets. Thus, following terminologies are used to specify tokens:

1) **Alphabets:** The set of symbols is called alphabets. Example any finite set of symbols $\Sigma = \{0,1\}$ is a set of binary alphabets.

2) **Strings:** Any finite sequence of alphabets is called a string. Length of string is the total number of occurance of alphabets. e.g, the length of string 'Kanchanpur' is 10. A string of zero length is known as empty string and is denoted by ε (epsilon).

3) **Language:** A language is considered as a finite set of strings over some finite set of alphabets. Computer languages are considered as finite sets, and mathematically set operations can be performed on them:

1) **Union:** It is defined as the set that consists of all elements belonging to either set A or set B or both. In regular expression + symbol is used to represent union operation.

$A = \{dog, ba, na\}$ and $B = \{house, ba\}$

then, $A \cup B = A + B = \{dog, ba, na, house\}$

ii) Concatenation: It is the operation of joining character strings end-to-end. In regular expression dot operator (.) is used to represent concatenation operation.

$A.B = \{doghouse, dogba, bahouse, baba, nahouse, naba\}$

iii) Kleen closure: The Kleene closure Σ^* gives the set of all possible strings of all possible lengths over Σ including $\{\Phi\}$.

iv) Positive Closure: The set Σ^+ is the infinite set of all possible strings of all possible lengths over Σ excluding $\{\Phi\}$.

Regular Expressions: Regular expressions are the algebraic expressions that are used to describe tokens of a programming language. It uses three regular operations called union, concatenation and star.

Examples: Given the alphabet $A=\{0,1\}$.

1) $1(1+0)^*0$ denotes the language of all strings that begins with a '1' and ends with a '0'.

2) $(01)^* + (10)^*$ denotes the set of all strings that describe alternating 1s and 0s.

[Note: Practice R.E for identifier in C, one dimensional array, two dimensional array & floating numbers. (6,10,11,12 no. in kec book under RE topic.)]

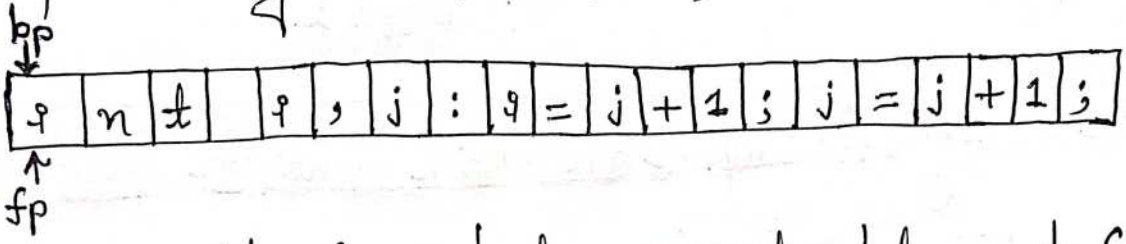
Recognition of Tokens:

A recognizer for a language is a program that takes a string w, and answers "Yes" if w is a sentence of that language, otherwise "NO." The tokens that are specified using RE are recognized by using transition diagram or finite automata (FA). Starting from the start state we follow the transition defined. If the transition leads to the accepting state, then the token is matched and hence the lexeme is returned, otherwise other transition diagrams are tried out until we process all the transition diagram or the failure is detected. Recognizer of tokens takes the language L and the string s as input and try to verify whether $s \in L$ or not. There are two types of Finite Automata.

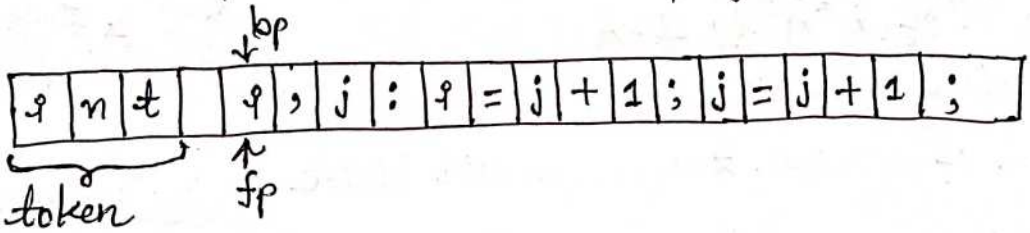
1). Deterministic Finite Automata (DFA).

2). Non Deterministic Finite Automata (NFA).

⊛. **Input Buffering:** Reading character by character from secondry storage is slow process and time consuming as well so, we use buffer technique to eliminate this problem and increase efficiency. The lexical analyzer scans the input from left to right one character at a time. It uses two pointers, begin ptr (bp) and forward ptr (fp) to keep track of the pointer of input scanned. Initially both the pointers point to the first character of the input string as shown below;



The forward ptr moves ahead to search for end of lexeme. As soon as the blank space is encountered, it indicates end of lexeme. In above example as soon as fp encounters a blank space the lexeme 'int' is identified. Then both bp and fp are set at next token as shown below and this process will be repeated for the whole program.

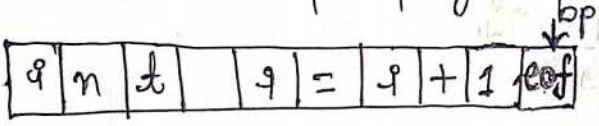


One Buffer Scheme: In this scheme, only one buffer is used to store the input string but the problem with this scheme is that if lexeme is very long then it crosses the buffer boundry, to scan rest of the lexeme the buffer has to be refilled.

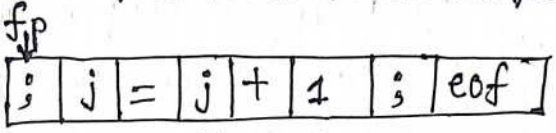
Two Buffer Scheme: In this scheme, two buffers are used to store input string and they are scanned alternately. When end of current buffer is reached the other buffer is filled. The only problem with this method is that if length of the lexeme is longer than length of the buffer then scanning input cannot be scanned completely.

Initially both the bp and fp are pointing to the first character of first buffer. Then the fp moves forward in search of

end of lexeme. As soon as blank character is recognized, the string between bp and fp is identified as corresponding token. To identify, the boundry of first buffer end of buffer character (eof) should be placed at the end of first buffer, similarly for second buffer also. Alternatively both the buffers can be filled up until end of the input program and stream of tokens is identified.



Buffer 1



Buffer 2.

⊛ Read Following basic topics from 4th sem note of TOC (Unit-2 and Unit-3):

1) Finite Automata.
2) Deterministic Finite Automata (DFA).
3) Non Deterministic Finite Automata (NFA).
4) Epsilon NFA (ε-NFA).
5) Minimization of DFA. (state partition method) (same TOC में पढ़ा गया)
6) Equivalence of Regular Expression and Finite Automata.
7) Reduction of Regular Expression to ε-NFA.
8) Converting ε-NFA to its equivalent DFA.

May not be asked in exam but these topics are necessary topics to understand for upcomming topics. these are basics

⊛ Design of a Lexical Analyzer: [Imp]

Among these two algorithms one is asked in exam. Here if we see NFA then, it is always ε-NFA

Lexical Analyzer can be designed using following two algorithms:

Algorithm1: Regular Expression → NFA → DFA (two steps: first RE to NFA, then NFA to DFA).

Algorithm2: Regular Expression → DFA (directly convert a regular expression into a DFA).

same

#Algorithm1:

i.e, Reduction of Regular Expression to ε-NFA that we read in TOC Unit-3

This consists of following two steps:

1) Regular Expression to NFA (Thomson's Construction):

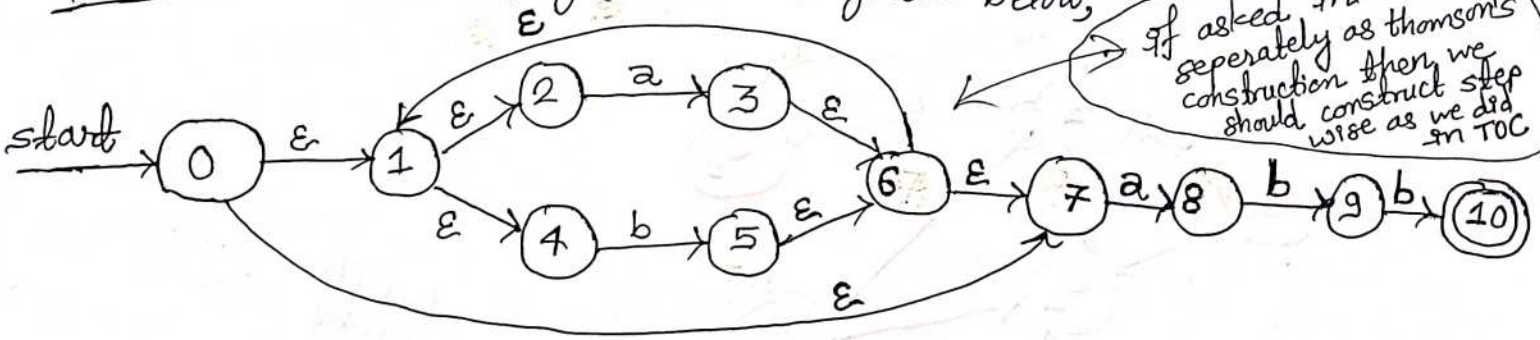
i.e, Converting ε-NFA to its equivalent DFA that we read in TOC Unit-2

2) Conversion from NFA to DFA (Subset Construction Algorithm):

Example: For Regular Expression $(a+b)^*abb$, first convert this RE to NFA, then convert resulting NFA to DFA.

Solution: The NFA of given RE is given below;

If asked in exam seperately as thomson's construction then we should construct step wise as we did in TOC



Now we convert above NFA to DFA as,

The starting state of DFA = S_0 = ε-closure (S_0) ⇒ $S_0 = \{0,1,2,4,7\}$

starting state र start state बाट ε लिएर कुन कुन state सम्म पुगेको हो त्यसको list

Since we have two input symbols a, b so we check for each input

$S_0 = 0,1,2,4,7$ S_0 मा a उनाउदा 3 र 8 मा जानेको हो

Mark S_0,

For a: ε-closure $(\delta(S_0, a))$ = ε-closure $(3,8) = \{1,2,3,4,6,7,8\} \rightarrow S_1$

For b: ε-closure $(\delta(S_0, b))$ = ε-closure $(5) = \{1,2,4,5,6,7\} \rightarrow S_2$

कुनै वटा set आएको वटा state लाई denote गर्न like here S_1

previous step मा आएको वटा set check गर्ने next step मा

Mark S_1,

For a: ε-closure $(\delta(S_1, a))$ = ε-closure $(3,8) = \{1,2,3,4,6,7,8\} \rightarrow S_1$

For b: ε-closure $(\delta(S_1, b))$ = ε-closure $(5,9) = \{1,2,4,5,6,7,9\} \rightarrow S_3$

must denote गरेको यदि DFA बनाउदा साबिलो होस् भनेर

Mark S_2,

For a: ε-closure $(\delta(S_2, a))$ = ε-closure $(3,8) = \{1,2,3,4,6,7,8\} \rightarrow S_1$

For b: ε-closure $(\delta(S_2, b))$ = ε-closure $(5) = \{1,2,4,5,6,7\} \rightarrow S_2$

Mark S_3,

For a: ε-closure $(\delta(S_3, a))$ = ε-closure $(3,8) = \{1,2,3,4,6,7,8\} \rightarrow S_1$

For b: ε-closure $(\delta(S_3, b))$ = ε-closure $(5,10) = \{1,2,4,5,6,7,10\} \rightarrow S_4$

Mark S_4,

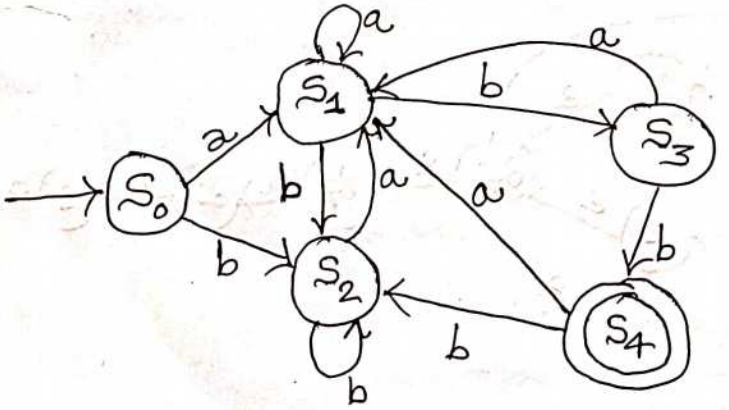
For a: ε-closure $(\delta(S_4, a))$ = ε-closure $(3,8) = \{1,2,3,4,6,7,8\} \rightarrow S_1$

For b: ε-closure $(\delta(S_4, b))$ = ε-closure $(5) = \{1,2,4,5,6,7\} \rightarrow S_2$

No new states here S_1, S_2 are already checked so we stop here. We stop when there are no any new states to check

S_0 is the starting state. S_4 is an accepting state of DFA since final state of NFA is 10 i.e, states containing 10 are member of final state of DFA. (Since $S_4 = \{1,2,4,5,6,7,10\}$).

Now, constructing DFA using above information:



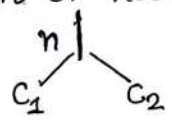
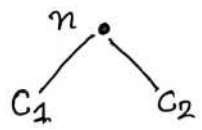
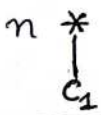
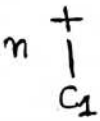
Note: Practice more examples from kec book

Algorithm 2 (Conversion from RE to DFA Directly):

Conversion steps: (for exam mostly numericals are asked theory for understanding only)

1. Augment the given regular expression by concatenating it with special symbol #.
2. Create the syntax tree for this augmented regular expression.
3. Then each alphabet symbol (including #) with be numbered as position numbers.
4. Compute functions nullable, firstpos, lastpos, and followpos.
5. Finally construct DFA directly from a regular expression by computing the functions nullable(n), firstpos(n), lastpos(n), and followpos(i) from the syntax tree.

Rules for calculating nullable, firstpos and lastpos:

Node n	nullable (n)	firstpos (n)	lastpos (n)
A leaf labelled ε	True	ϕ	ϕ
A leaf with position i	False	{i} (position of leaf node)	{i}
An or node 	Nullable (c_1) or Nullable (c_2).	firstpos(c_1) ∪ firstpos(c_2)	lastpos(c_1) ∪ lastpos(c_2)
A concatenation node 	Nullable (c_1) and Nullable (c_2).	If (Nullable(c_1)) firstpos(c_1) ∪ firstpos(c_2). else firstpos(c_1)	If(Nullable(c_2)) lastpos(c_1) ∪ lastpos(c_2). else lastpos(c_2).
A star node 	True	firstpos(c_1)	lastpos(c_1)
A +ve closure node 	False	firstpos(c_1)	lastpos(c_1)

Now we calculate followpos for each i we numbered. Now we can construct DFA with starting state S_1 = firstpos(root) from syntax tree and marking each state for each input until no new unmarked states occur.

Example: Convert the regular expression $(a|b)^*a$ into equivalent DFA by direct method.

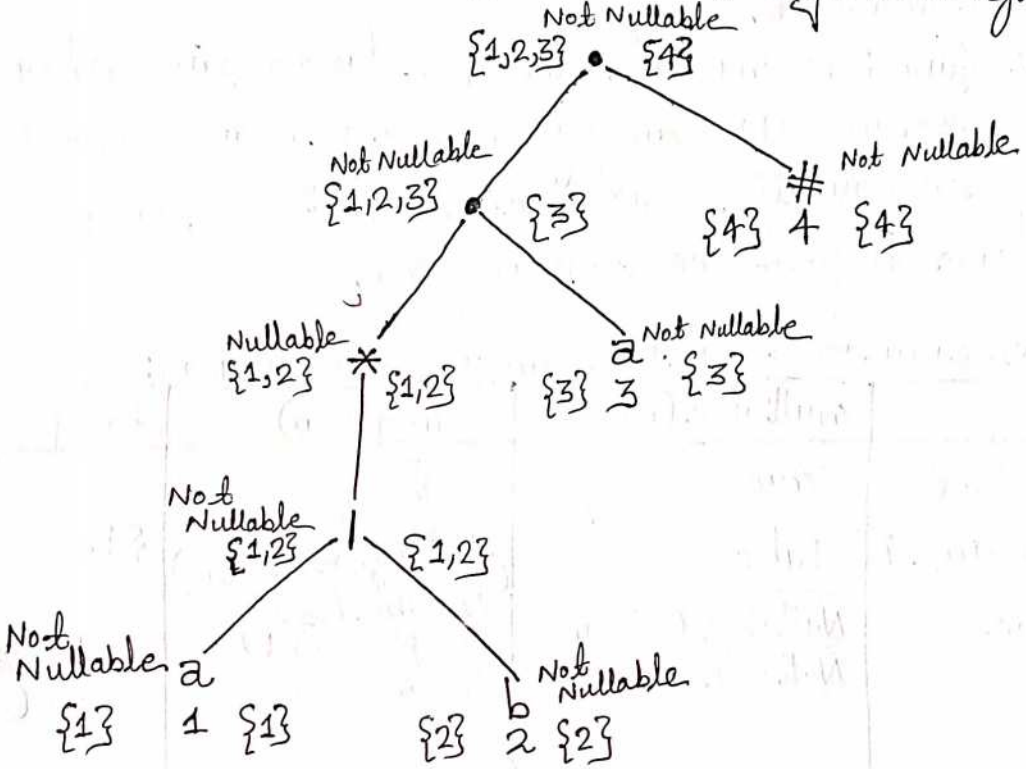
Solution:

Step1: At first we augment the given regular expression as,

$(a|b)^*.a.\#$ ← last मा # राखे augment हुन्छ। हुने operator दुई product form मा हुने भने दुवैलाई dot operator हुन्छ।

1 2 3 4 ← alphabets including # numbered

Step2: Now we construct syntax tree of augmented regular expression as,



Step3: Now we compute followpos as,

followpos(1) = {1,2,3}
followpos(2) = {1,2,3}
followpos(3) = {4}
followpos(4) = {∅} ← empty

Step4: Now we start with starting state as,

S_1 = firstpos(root node of syntax tree) = {1,2,3}

Mark S_1,

For a: followpos(1) ∪ followpos(3) = {1,2,3,4} → S_2 ← marked as new state using variable or state name S_2

Since we are marking for a for S_1 = {1,2,3}. Now look at step1 where where a occurs in 1,2,3. Here a occurs in 1 & 3 so Union of 1 & 3

for b: followpos(2) = {1,2,3} → S_1

In step 1 between 1,2,3 b occurs at 2 only

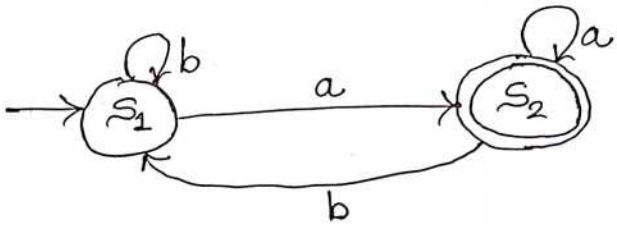
Mark S_2;

For a: followpos(1) ∪ followpos(3) = {1,2,3,4} → S_2

for b: followpos(2) = {1,2,3} → S_1.

No new states occur so we stop marking here. Accepting state means state containing position of # (i.e, 4). So, here S_2 = {1,2,3,4} is accepting state.

Now, based on the above information, resulting DFA of given regular expression is as follows:



Practice these questions also if any confusion or want to try to match answer then refer ref book for solution page no 37.

Q1. Convert the regular expression $(a|\varepsilon)bc^*$ into equivalent DFA by direct method.

Q2. Convert the regular expression $ba(a+b)^*ab$ into equivalent DFA by direct method.

possibility of asking in short note for 2.5 marks

⊛ Flex: An Introduction

Flex is a tool for generating scanners. A scanner is a program which recognizes lexical patterns in text. The flex program reads the given input files, or its standard input if no file names are given, for a description of a scanner to generate. The description is in the form of pairs of regular expressions and C code, called rules. Flex generates as output a C source file, 'lex.yy.c' by default, which defines a routine yylex(). This file can be compiled and linked with the flex runtime library to produce an executable. When the executable is run, it analyzes its input for occurrences of the regular expressions. Whenever it finds one, it executes the corresponding C code.

Flex Specification: A flex specification consists of three parts:

Regular definitions, C declarations in % { %}

%%

Translation rules

%%

User defined auxiliary procedures

This is syntax. %% are opening and closing tags.

The translation rules are of the form:

P_1	{action 1}
P_2	{action 2}
. . .	. . . . .
P_n	{action n}

In all parts of the specification comments of the form /* comment text */ are permitted.

Syntax Analyzer

about 20 marks को सोचह, तो आए

Syntax Analysis: All programming languages have certain syntactic structures. We need to verify the source code written for a language is syntatically valid. The validity of the syntax is checked by the syntax analysis. Syntaxes are represented using context free grammar (CFG), or Backus Naur Form (BNF). Parsing is the act of performing syntax analysis to verify an input program's compliance with the source language. The purpose of syntax analysis or parsing is to check that we have a valid sequence of tokens.

Syntax analyzer and Parser are same thing

Role of Syntax Analyzer/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. It has to report any syntax errors if occurs.

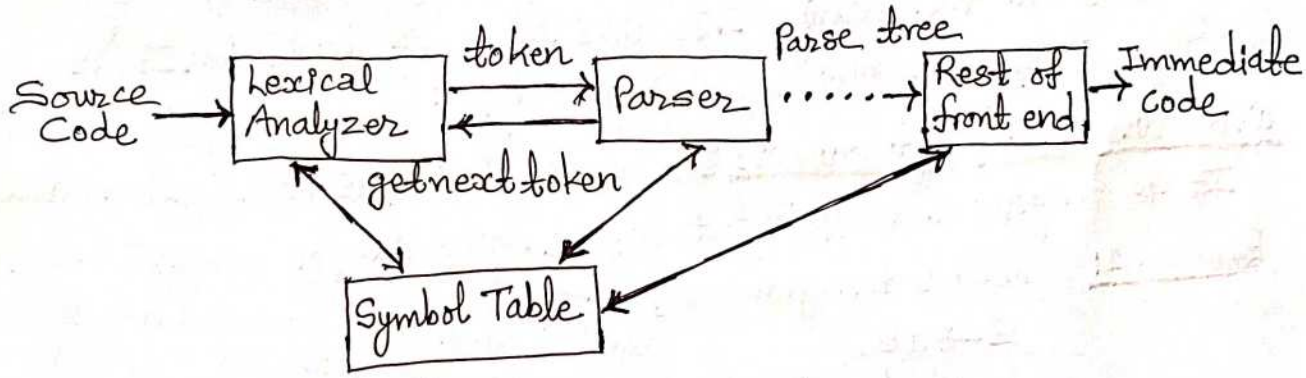


Fig: Role of Parser in a compiler model.

The tasks of parser can be expressed as;
- → Analyzes the context free syntax.
- → Generates the parse tree.
- → Provides the mechanism for context sensitive analysis.
- → Determine the errors and tries to handle them.

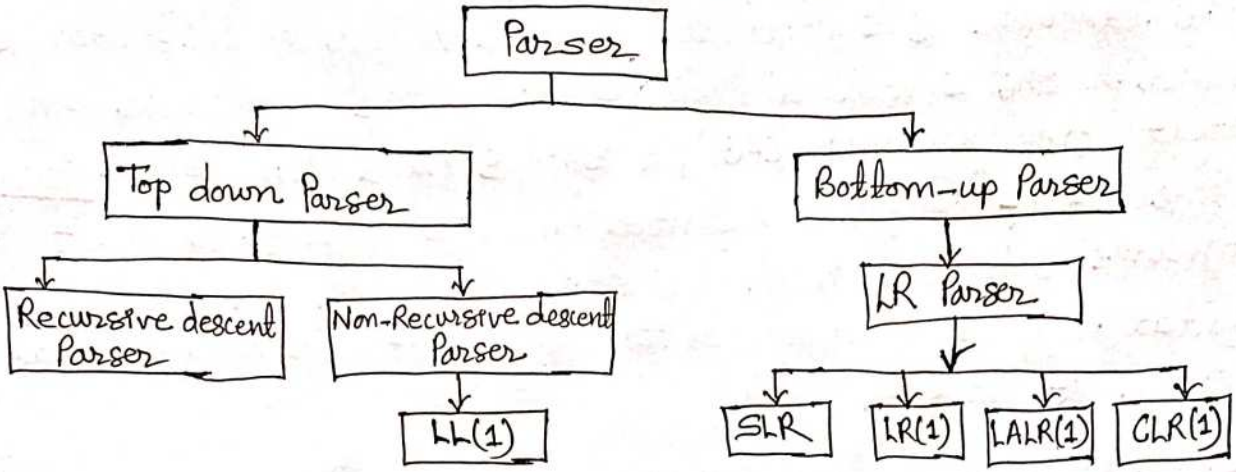
Basic Topics to understand from TOC Unit-4 or Kec Book:

1. Concept of context free grammar including production rules of language.
2. Derivations (leftmost and rightmost)
3. Parse Trees
4. Ambiguity of a Grammar.

These topics are not asked in exam maybe rarely Parse tree asked but concept is needed for upcomming important topic Parsing.

theory related to this are less imp mostly Numericals are imp.

Parsing: Parser is a compiler that is used to break the data into smaller elements coming from lexical analysis phase. A parser takes input in the form of sequence of tokens and produces output in the form of parse tree.



1) Top down Parser:

Top-down parser is a parser which generates parse for the given input string with the help of grammar productions by expanding the non-terminals i.e, it starts from the start symbol and ends on the terminals. It uses left most derivation. It is further classified into following two types:

a) Recursive descent parser: It is also known as backtracking parser. It is a general inefficient technique, only used for small production rules.

Example 1: Consider the grammar,

$S \rightarrow aBc$

$B \rightarrow bc/b$

Input string: abc

Solution:

for solving this every time we use three columns input, output & Rule. सुरुमा input मा दिइएको input string राख्ने output मा production rule मा starting symbol जुन छ त्यो राख्ने / छ rule मा starting symbol मा भएको production rule राख्ने

Input	Output	Rule used
abc	S	use $S \rightarrow aBc$
abc	aBc	Match symbol a
bc	Bc	use $B \rightarrow bc$
bc	bcc	Match symbol b
c	cc	Match symbol c
$\emptyset$	c	Dead end, backtrack.
bc	Bc	use $B \rightarrow b$
bc	bc	Match symbol b
c	c	Match symbol c
$\emptyset$	$\emptyset$	Accepted

backtrack गरेको

above step मा $S \rightarrow aBc$ rule use गरेकोले S लाई aBc ले replace गरेको

left to right corresponding symbol match गर्ने match नभए त्यो symbol delete गर्ने there a is deleted

now we have capital B which is non terminal so it should be reduced to terminal using production rule

दुईवटै $\emptyset$ भए accept हुन्छ अन्यथा backtrack गर्छ।

backtrack गर्दा त्यो भन्दा पहिला production rule जा use भाको छ त्यहाँ गर्ने so हामिले 3rd step मा गऱ्यौं

Example2: Consider the grammar,

$S \rightarrow aBc \mid aaB$

$B \rightarrow bc \mid a$

Input string: aaa

Solution:

Input	Output	Rule used
aaa	S	use $S \rightarrow aBc$
aaa	aBc	Match symbol a
aa	Bc	use $B \rightarrow bc$
aa	bcc	Dead end, backtrack
aa	Bc	use $B \rightarrow a$
aa	ac	Match symbol a
a	c	Dead end, backtrack
aa	Bc	Dead end, backtrack
aa	Bc	Dead end, backtrack
aaa	S	use $S \rightarrow aaB$
aaa	aaB	Match symbol a
aa	aB	Match symbol a
a	B	use $B \rightarrow bc$
a	bc	Dead end, backtrack
a	B	use $B \rightarrow a$
a	a	Match symbol a
Φ	Φ	Accepted

① सुरुको दुईवटै symbol terminal (i.e, small) हुँदा र match भएन भने dead end हुन्छ recently used rule मा backtrack हुन्छ

② back track गरेर input र output copy गर्यो recently used production rule को

③ B replaced by a by rule and symbol a matched so will get deleted in next step.

④ dead end आएर recent production rule $B \rightarrow a$ मा गयो जसमा input र output aa र Bc हुन् हामिले B लाई reduce गर्नु पर्ने terminal symbol (i.e, small) मा but $B \rightarrow bc$ र $B \rightarrow a$ already check गरिसक्यौं ∴ आएन अरु rule चैन B gives so फेरि backtrack गरि माथिल्लो production $S \rightarrow aBc$ मा गयौं,

⑤ $S \rightarrow aBc$ already check गरेको but ∴ आएन so अब aaB राखेर whole process गर्दा

⊛. Left Recursion:

A grammar becomes left-recursive if it has any non-terminal 'A' whose derivation contains 'A' itself as the left-most symbol. Left recursion becomes problem for top-down parsers because left recursion leads to infinite loop so we reduce or eliminate it before solving top-down parsers. A grammar is left recursive if it has a non-terminal A such that there is a derivation:

$$A \rightarrow A\alpha \quad \text{for some string } \alpha.$$

Let we has production as follows:

$$A \rightarrow A\alpha_1 \mid A\alpha_2 \mid A\alpha_3 \mid \ldots \mid A\alpha_n \mid \beta_1 \mid \beta_2 \mid \beta_3 \mid \ldots \mid \beta_n$$

where, $\beta_1, \beta_2, \ldots \beta_n$ do not start with A

$A\alpha_1$ to $A\alpha_n$ left recursion occurs ∴ β_1 to β_n does not occur

β means it can be terminal or non-terminal symbol

Now we eliminate immediate left recursion as;

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

$$A' \rightarrow \alpha_1 A' \mid \alpha_2 A' \mid \ldots \mid \alpha_n A' \mid \varepsilon$$

यो general form हो left recursion eliminate गर्ने

माथिबाट left recursion नभएको Part A' पछाडि लिएको

माथिबाट left recursion symbol हटाई बाकी A' सँग लिएको (i.e A) अन्त्यमा ε पाउने last मा ε पाउने

Example1: Eliminate left recursion from following grammar,

$S \to SBc|SaB|ab|ba|a|b$

$B \to bc|a$

→ SBc|SaB left recursion part because S→Soc form ie A→Aα

Solution:

left recursion नभएको part र S'

$S \to abS'|baS'|aS'|bS'$

$S' \to BcS'|aBS'|\varepsilon$

$B \to bc|a$

left recursion भएको part with S' recursion symbol हटाएर last मा ε राखेर as in general form

यसमा left recursion छैन so copy as it is

Example2: Eliminate left recursion from following grammar,

$E \to E+T|T$

$T \to T*F|F$

$F \to id|(E)$

Solution:

$E \to TE'$

$E' \to +TE'|\varepsilon$

$T \to FT'$

$T' \to *FT'|\varepsilon$

$F \to id|(E)$

Recursive E+T मा E छ so, E skip+T taken and E' added with ε as in general form

non-recursive part with T'

Non-Immediate left recursion:

Example: Let's take a grammar with non-immediate left recursion.

$S \to Aa|b$

$A \to Sc|d$

directly left recursion नभएको but कुनै अरु अरु production राखेर check गर्दा left recursion आउने, यस्तो लाई non-immediate left recursion भनिन्छ। यसलाई solve गर्न कुनै अरु production rule राखेर पहिला left recursion बनाउने अनि माथि को जस्तै solve गर्ने।

This grammar is not immediately left-recursive but is still left recursive, So, at first we make immediate recursive as,

$S \to Sca|da|b$

$A \to Sc|d$

A मा स्क्रोटि Sc राख्दा अर्को चोटि d since A→Sc|d

Now, eliminate left recursion as,

$S \to daS'|bS'$

$S' \to caS'|\varepsilon$

$A \to Sc|d$

production को right side rule हेर्ने same symbol बाट start भएको छ भने (more than 1 rule) then, it is called left-factorial grammar

⊛. Left-factoring: If more than one production rules of a grammar have a common prefix string, then the top-down parser cannot make a choice as to which of the production it should take to parse the string. This grammar is called left factoring grammar.

Let's take an example;

$$A \to \alpha\beta_1|\alpha\beta_2|\alpha\beta_3|\ldots|\alpha\beta_n|\gamma$$

Now eliminate left factoring as;

General form

$$A \to \alpha(\beta_1|\beta_2|\beta_3|\ldots|\beta_n)|\gamma$$

repeat हुने start symbol common हटाएर left-factoring गरिन्छ.

The resulting grammar with left factoring free is;

$A \to \alpha A'|\gamma$

$A' \to \beta_1|\beta_2|\beta_3|\ldots|\beta_n$

Example1: Eliminate left factorial from following grammar:

$S \rightarrow iEtS \mid iEtSeS \mid a$

$B \rightarrow b$

Solution:

यहाँ मात्र common लिएर फेरि E लेख्ने left factorial हुन्छ/so common सबै लिने/so, iEtS पुरै लिदा left factorial रहँदैन

$S \rightarrow iEtS(\varepsilon \mid eS) \mid a$

$B \rightarrow b$

The resulting grammar with left factorial free is,

$S \rightarrow iEtSS' \mid a$

$S' \rightarrow \varepsilon \mid eS$

$B \rightarrow b$

Example 2: Eliminate left factorial from following grammar:

$S \rightarrow bSSaaS \mid bSSaSb \mid bSb \mid a$

Solution:

$S \rightarrow bSS' \mid a$ ← सबै maximum मा देखा bS तिनवटा मा common, so bS common लिएको

$S' \rightarrow SaaS \mid SaSb \mid b$ ← Sa फेरि common छ so, फेरि लगाउने

The resulting grammar with left factorial free is,

$S \rightarrow bSS' \mid a$

$S' \rightarrow SaS'' $

$S'' \rightarrow aS \mid Sb \mid b$

b) Non-Recursive Descent Parser:

A form of recursive-descent parsing that does not require any back-tracking is known as predictive parsing. It is also called LL(1) parsing table technique since we would be building a table for string to be parsed. It has capability to predict which production is to be used to replace input string.

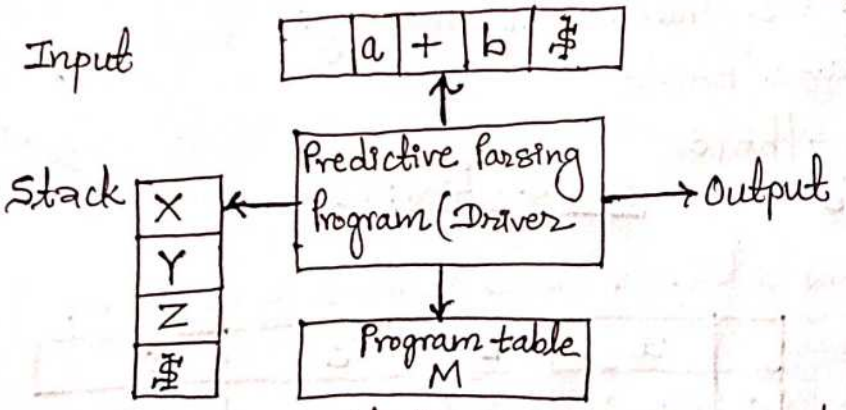


Fig: Model of a non-recursive predictive parser.

- **Input Buffer:** It contains the string to be parsed followed by a symbol $.
- **Stack:** It contains sequence of grammar symbols with $ at bottom.

- **Parsing table:** It is a two dimensional array M[A, a] where 'A' is non-terminal and 'a' is terminal symbol.
- **Output stream:** A production rule representing a step of the derivation sequence of the string in the input buffer.

⊛ Recursive predictive descent parser VS. Non-recursive predictive descent parser:

Recursive predictive descent parser	Non-recursive predictive descent parser
It is a technique which may require backtracking process.	It is a technique that does not require any kind of backtracking.
It uses procedures for every non terminal entity to parse strings.	It finds out productions to use by replacing input string.
It is a type of top-down parsing built from a set of mutually recursive procedures where each procedure implements one of non-terminals of grammars.	It is a type of top-down approach, which is also a type of recursive parsing that does not uses technique of backtracking.
It contains several small functions one for each non-terminals in grammar	The predictive parser uses a look ahead pointer which points to next input symbols to make it parser back tracking free, predictive parser puts some constraints on grammar.
It accepts all kinds of grammars.	It accepts only a class of grammar known as LL(k) grammar.

Example: (To demonstrate Non-recursive descent parser):

Consider the grammar G1 given by:

$S \rightarrow aAa \mid BAa \mid \varepsilon$

$A \rightarrow cA \mid bA \mid \varepsilon$

$B \rightarrow b$

Input string: bcba

Solution:

Parsing table for above grammar is as follows:

	a	b	c	$
S	S→aAa	S→BAa		S→ε
A	A→ε	A→bA	A→cA	
B		B→b		

Table बनाने के topic को LL(1) में construct करना है। For now consider as we know to draw this table or this table is given in question

Now do not focus on how this table is constructed just use this table

Now parsing of input string w = bcba using non-recursive descent parser is as follows:

① stack को सुरुमा $ symbol then start symbol of grammar लेखिन्छ

Stack	Remaining input	Action
$S	bcba$	choose S→BAa
$aAB	bcba$	choose B→b
$aAb	bcba$	match b
$aA	cba$	choose A→cA
$aAc	cba$	match c
$aA	ba$	choose A→bA
$aAb	ba$	match b
$aA	a$	choose A→ε
$a	a$	match a
$	$	Accept

② input को सुरुमा input string र last मा $ symbol हुन्छ, Stack मा last character र input मा first character जाँच गर्दै

③ माथिको table मा stack को top symbol र input को first symbol हुँदा प्रयोग rule कुन रहेछ भनेर हेरिन्छ। Here we have stack top = S 1st input = b So, S र b को table gives BAa.

④ We have S in stack top but we choose S→BAa So, S is replaced by BAa but as we know stack is Last in first out (LIFO) so we have to store it in reverse order as aAB.

Now top of stack contains B and start of input contains b so according to table rule is B→b So we choose B→b

⑤ Now top of stack contains b and first input also b so both matched and b is deleted

⑥ Similarly we proceed and finally if we get both stack and input as $ symbol only then we accept string otherwise reject

✱ Constructing LL(1) Parsing Table: [V. Imp]

The parse table construction requires two functions: **FIRST** and **FOLLOW**.

A grammar G is suitable for LL(1) parsing table if the grammar is free from left recursion and left factoring.

A grammar → eliminate left recursion → eliminate left factor → Grammar is suitable now for predictive parsing (LL(1) grammar)

To compute LL(1) parsing table, at first we need to compute FIRST and FOLLOW functions.

Compute FIRST: FIRST(α) is a set of terminal symbols which occur as first symbols in strings derived from α where α is any string of grammar symbols.

Rules:

↳ If 'a' is terminal, then FIRST(a) is {a}.

↳ If $A \to \varepsilon$ is a production, then FIRST(A) is ε.

↳ For any non-terminal A with production rules $A \to \alpha_1 | \alpha_2 | \alpha_3 | \dots | \alpha_n$ then $FIRST(A) = FIRST(\alpha_1) \cup FIRST(\alpha_2) \cup \dots\dots \cup FIRST(\alpha_n)$.

↳ If the production rule of the form, $A \to \beta_1 \beta_2 \beta_3 \dots \beta_n$ then,

$$FIRST(A) = FIRST(\beta_1 \beta_2 \beta_3 \dots \beta_n).$$

Example1: Find FIRST of following grammar symbols,

$R \to aS | (R)S$

$S \to +RS | aRS | *S | \varepsilon$

Solution:

We calculate FIRST for each symbol in production

terminal symbol so first of that symbol is same that symbol by rule

opening symbol first comes and these symbols are treated as terminal

$FIRST(aS) = FIRST(a) = \{a\}$ $\quad FIRST((R)S) = FIRST(() = \{(\}$

$FIRST(+RS) = FIRST(+) = \{+\}$ $\quad FIRST(aRS) = FIRST(a) = \{a\}.$

$FIRST(*S) = FIRST(*) = \{*\}$ $\quad FIRST(\varepsilon) = FIRST(\varepsilon) = \{\varepsilon\}.$

$FIRST(R) = \{FIRST(aS) \cup FIRST((R)S)\} = \{a, (\}$

first of aS and (R)S already found so now we can just place them.

$FIRST(S) = \{FIRST(+RS) \cup FIRST(aRS) \cup FIRST(*S) \cup FIRST(\varepsilon)\}$

$= \{+, a, *, \varepsilon\}.$

Example2: Find FIRST of following grammar symbols,

$E \to TE'$

$E' \to +TE' | \varepsilon$

$T \to FT'$

$T' \to *FT' | \varepsilon$

$F \to (E) | id$

Solution:

opening brace

$FIRST(F) = \{FIRST((E)) \cup FIRST(id)\} = \{(, id\}$ $\quad FIRST(id) = \{id\}$

$FIRST((E)) = \{(\}$

$FIRST(T') = \{*, \varepsilon\}$

$FIRST(E') = \{+, \varepsilon\}$

$FIRST(TE') = FIRST(T) = \{(, id\}$ $\quad FIRST(T) = FIRST(F) = \{(, id\}$

$FIRST(E) = FIRST(T) = \{(, id\}$

$FIRST(\varepsilon) = \{\varepsilon\}.$

$FIRST(+TE') = FIRST(+) = \{+\}$

$FIRST(*FT') = FIRST(*) = \{*\}$

$FIRST(FT') = FIRST(F) = \{(, id\}$

$FIRST((E)) = FIRST(() = \{(\}$

Compute FOLLOW: FOLLOW(A) is the set of terminals that can immediately follow non terminal A except ε.

Rules:

↳ If A is a starting symbol of given grammar then FOLLOW(A) = {$}.

↳ For every production $B \to \alpha A \beta$, where α and β are any string of grammar symbols and A is non terminal, then everything in FIRST(β) except ε is FOLLOW(A).

β को गुआमा ε हुदा αA मै हुन्छ

↳ For every production $B \to \alpha A$, or a production $B \to \alpha A \beta$, FIRST(β) contains ε, then everything in FOLLOW(B) is FOLLOW(A).

Example 1: Compute FOLLOW of the following grammar.

Follow compute गर्दा left side को symbol को मात्र मतर लि पुग्छ

$R \to aS \mid (R)S$

$S \to +RS \mid aRS \mid *S \mid \varepsilon$

follow find गर्दा जसको follow find गर्नुहो, right side मा त्यो letter भएको production मात्र लिनुहो। Here R को निकाल्दा $R \to (R)S$, $S \to aRS$ मात्र लिनुहोस् → $+RS$, ε

Solution:

$FOLLOW(R) = \{FOLLOW(R)S \cup FOLLOW(+RS) \cup FOLLOW(aRS)\}$

according to 2nd rule

$= \{FIRST()S \cup FIRST(S) \cup FOLLOW(S)\}$

We have aRS but $S \to \varepsilon$ so if we put ε in place of S we get aR. So, 3rd rule used

$= \{\$,), +, a, *\}$

Since we don't know follow of S now so we calculate it below seperately

R starting symbol भएकोले $ थपिएको

FIRST()S is)

FIRST(S) is already computed in FIRST section example 1 so, we directly use here FIRST(S) = {+, a, *, ε}

aRS मा ε भनेको भए 2nd rule use हुन्थ्यो FIRST(S) हुन्थ्यो but FIRST(S) set मा already आइसकेको थियो so repeat हुने थिएन FIRST()S ∪ FIRST(S) यो दुई term मात्र हुन्थ्यो।

we do not use ε in FOLLOW

$FOLLOW(S) = \{FOLLOW(R)\}$

$= \{\$,), +, a, *\}$

Follow(S) same as follow(R) आयो so माथि थपेनै किनकि set मा value repeat हुँदैनन्। फरक आको भए माथि FOLLOW(S) को ठाउँमा value हरु थपथ्यौं।

Example 2: Compute FOLLOW of the following grammar.

$E \to TE'$

$E' \to +TE' \mid \varepsilon$

$T \to FT'$

$T' \to *FT' \mid \varepsilon$

$F \to (E) \mid id$

left side symbols E, E', T, T', र F को Follow निकाल्नुहो

right side E भएको production रहेछ मात्र ६ so त्यो मात्र लिएको $F \to (E)$

Solution:

$FOLLOW(E) = FIRST())$

E लाई follow गर्ने closing brace which is terminal. Terminal को First terminal नै हुन्छ।

$= \{\$,)\}$

E starting Symbol पनि हो so $ add गर्नुहो

We have two productions for this $E \to TE'$ and $E' \to +TE'$

E' को follow निकाल्दै छौं, $E' \to \varepsilon$ छ but E' मै राख्न मिलेन i.e, निकालिने symbol र ε राख्ने symbol same नाए ε राख्दैनौं।

$FOLLOW(E') = \{FOLLOW(E) \cup FOLLOW(E')\}$

$E \to TE'$ मा E' पछि केहि छैन so, FOLLOW(E) similar for E'

$= \{\$,)\}$

follow(E) को value लिएको माथिबाट। FOLLOW of E' निकाल्दै छौं so Follow(E') को निकाल्दैनौं आफ्नै follow नाएर

$FOLLOW(T) = \{FOLLOW(TE') \cup FOLLOW(+TE') \cup FOLLOW(T) \cup FOLLOW(E')\}$

we have following productions for this
$E \to TE'$, $E' \to +TE'$
But we also have $E' \to \varepsilon$
so putting in above two we get two new productions as
$E \to T$, $E' \to +T$

$= \{FIRST(E') \cup FOLLOW(E) \cup FOLLOW(E')\}$

$E \to TE'$
$E' \to +TE'$
gives FIRST(E') by 2nd rule

$= \{+, \$,)\}$

first of E' is + already calculated in FIRST Section

FOLLOW(E) मा $ and) already calculated above, FOLLOW(E') मा $ already in set so not necessary to include

$E \to T$ gives FOLLOW(E) by 3rd rule

by 3rd rule $E' \to +T$ gives FOLLOW(E')

$FOLLOW(T') = \{FOLLOW(FT') \cup FOLLOW(*FT')\}$

we have two productions for this: $T \to FT'$ and $T' \to *FT'$
Also we have $T' \to \varepsilon$ but T' के निकालिरहेछौं follow so ε राख्नु पर्दैन as we did for E' above

$= \{FOLLOW(T) \cup FOLLOW(T')\}$

by 3rd rule

by 3rd rule. but we can neglect this, we are calculating Follow(T) itself so.

$= \{+,), \$\}$

value of FOLLOW(T) that we already calculated above

$FOLLOW(F) = \{FOLLOW(FT') \cup FOLLOW(*FT') \cup FOLLOW(F) \cup FOLLOW(*F)\}$

$= \{FIRST(T') \cup FOLLOW(T')\}$

by 2nd rule

$= \{+, *,), \$\}$

We have two production for FOLLOW(F) as:
$T \to FT'$ and $T' \to *FT'$
but we also have $T' \to \varepsilon$ in grammar so, we put and get two more:
$T \to F$ and $T' \to *F$

Note: LL(1) Parsing table construct को लागि FIRST र FOLLOW find गर्दा At first left recursion र left factorial छ कि छैन check गर्ने। नभए directly FIRST र FOLLOW निकाल्ने। भए पहिला left recursion र left factorial reduce गर्ने (that we already read) अनि FIRST र FOLLOW को लागि same process proceed गर्ने।

FOLLOW निकाल्दा कुनै symbol को, त्यो symbol production को right side मा कुनै ठाउँमा पनि नभेटिए त्यसको follow start symbol नाए $ मात्र हुन्छ अरु भए केहि पनि हुँदैन empty.

We have calculated FIRST and FOLLOW, now we can construct LL(1) parsing table easily as in the following examples:

Example1: Construct LL(1) parsing table of following grammar.

$R \rightarrow aS \mid (R)S$

$S \rightarrow +RS \mid aRS \mid *S \mid \varepsilon$

Solution:

Non-terminals	Terminal Symbols					
	a	(	)	+	*	$
R	$R \rightarrow aS$	$R \rightarrow (R)S$				
S	$S \rightarrow aRS$ $S \rightarrow \varepsilon$		$S \rightarrow \varepsilon$	$S \rightarrow +RS$, $S \rightarrow \varepsilon$	$S \rightarrow *S$, $S \rightarrow \varepsilon$	$S \rightarrow \varepsilon$

(1) माथिको production हरु हेर्ने non-terminal जति सबै यो side लेख्ने

(2) माथिको production or grammar हेर्ने terminal हरु सबै लेख्ने र $ पनि आफ्नो last मा

(3) Now fill गर्न सुरु गर्‍यौं, so R ले दिने production हेर्‍यौं माथिको grammar मा, $R \rightarrow aS$ र $R \rightarrow (R)S$ दुवै। Production मा दुई case आउन सक्दछन् एउटा ε भनेको आर्को ε नभएको, ε नभएको आर (i.e, $A \rightarrow \alpha$ form where α can be terminals and non-terminals 1 or more than one) त्यतिबेला FIRST(α) हेर्ने हो। For eg. $R \rightarrow aS$ मा ε नभएको case हो, so FIRST(aS) हेर्‍यौं जुन हामिले पहिले नै निकालेका थियौं जसको value {a} हो so $R \rightarrow aS$, 'R' row and 'a' column मा हुने भयो। Same process for $R \rightarrow (R)S$, $S \rightarrow +RS$, $S \rightarrow aRS$ and $S \rightarrow *S$.

ε भनेको case हो भने, (i.e, $A \rightarrow \varepsilon$) त्यतिबेला FOLLOW(A) हेर्ने हो। For eg. $S \rightarrow \varepsilon$ हो last production हाम्रो so we see FOLLOW(S) which we already calculated and it has value {$,), +, a, *} हो, so S row अनि यी सबै symbol भनेको तल $S \rightarrow \varepsilon$ production हुने भयो।

(4) हामिले LL(1) parsing table त बनायौं but here एउटै cell मा more than 1 production पनि हो so in this type of case, the given grammar is not feasible for LL(1) parser. एउटा cell मा एउटा मात्र production भएको बेला LL(1) parser को लागि feasible हुन्छ।

Example2: Construct LL(1) parsing table for following grammar

$E \rightarrow TE'$

$E' \rightarrow +TE' \mid \varepsilon$

$T \rightarrow FT'$

$T' \rightarrow *FT' \mid \varepsilon$

$F \rightarrow (E) \mid id$

Solution:

Non-terminals	Terminal Symbols					
	+	*	(	)	id	$
E			E→TE'		E→TE'	
E'	E'→+TE'			E'→ε		E'→ε
T			T→FT'		T→FT'	
T'	T'→ε	T'→*FT'		T'→ε		T'→ε
F			F→(E)		F→id	

2. Bottom-up Parser:

→ यो topic बाट पनि कम्तिमा दुई question सोध्न सकिन्छ 3 पनि सोध्न / यो topic मा shift-reduce parsing, SLR, LR(1), LALR(1) पढ्नुहोला

Bottom-up Parser is the parser which generates the parse tree for the given input string with the help of grammar productions by starting from input string and ends on the start symbol, by the reduction process. Reduction is the process of replacing a substring by a non-terminal in bottom-up parsing. It is the reverse process of production.

Example: Consider the grammar

S→aABe
A→Abc|b
B→d

→ Production मा left side को symbol लाई right side को symbol ले replace गरिन्छ / but Reduction is just opposite. rightside को symbol लाई left side को symbol ले replace गरिन्छ

Now, the sentence abbcde can be reduced to S as follows:

abbcde
aAbcde (replacing b by using A→b)
aAde (replacing Abc by using A→Abc)
aABe (replacing d by using B→d)
S (replacing aABe by using S→aABe)

Hence, S is the starting symbol of grammar.

(short note मा सोध्न सक्छ यो) (basic terminology हो bottom-up parsing मा use हुने) (right side को terminal symbol जुन non-terminal symbol मा reduce हुन्छ, त्यो symbol लाई handle भनिन्छ।)

⊛ Handle:

A substring that can be replaced by a non-terminal when it matches its right sentential form is called a handle. If the grammar is unambigous, then every right-sentential form of the grammar has exactly one handle.

Example: Let we have production as: E→E+T|T, Now if we reduce E+T to E then, E+T is handle. Similarly let we have production as; F→(E)|id, Now if we reduce id to F then, id is handle.

2) Shift-Reduce Parsing:

A shift reduce parser tries to reduce the given input string into the starting symbol. At each reduction step, a substring of the input matching to the right side of a production rule is replaced by non-terminal at the left side of that production rule. The process of reducing the given input string into the starting symbol is called shift-reduce parsing.

A string ——Reduced to——→ the starting symbol.

Stack Implementation of Shift-Reduce Parser:

(यो theory हरु understand को लागि मात्र exam मा numerical आउछ can be escaped)

There are mainly following four basic operations used in shift reduce parser:

Shift: This involves moving of symbols from input buffer onto the stack.

Reduce: If the handle appears on top of the stack then, it's reduction by using appropriate production rule is done i.e, RHS of production rule is popped out of stack and LHS of production rule is pushed onto the stack.

Accept: If only start symbol is present in the stack and the input buffer is empty then, the parsing action is called accept. Accept means successful parsing is done.

Error: This is the situation in which the parser can neither perform shift action nor reduce action and not even accept action.

Algorithm:

1. Initially stack contains only the sentinel \$, and input buffer contains the input string w\$.

2. While stack not equal to $S do
   a. While there is no handle at the top of the stack, do shift input buffer and push the symbol onto the stack.
   b. If there is a handle on the top of the stack, then pop the handle and reduce the handle with its non-terminal and push it onto stack.
3. Done.

Example 1: Use the following grammar

$S \rightarrow S+S \mid S*S \mid (S) \mid id$

Perform Shift Reduce parsing for input string: id+id+id

Note that $S \rightarrow E$ are different & $S \rightarrow (E)$ not same

production rule को right side तिर जे जे हुन् त्यो सबै handle हुन् like S+S is one, S*S is another, (S) and id are also handle.

Solution:

Stack	Input Buffer	Parsing Action
$	id+id+id$	Shift id
$id	+id+id$	Reduce by S→id
$S	+id+id$	Shift +
$S+	id+id$	Shift id
$S+id	+id$	Reduce by S→id
$S+S	+id$	Shift +
$S+S+	id$	Shift id
$S+S+id	$	Reduce by S→id
$S+S+S	$	Reduce by S→S+S
$S+S	$	Reduce by S→S+S
$S	$	Accept

सुरुमा stack empty हुन्छ $ मात्र हुन्छ ↔ Input buffer मा input string राख्छौं last मा $ symbol पनि

Parsing action मा algorithm अनुसार mostly shift र Reduce operation हुन्छ।

Handle देख्न stack मा र input buffer empty भयो भने त्यतिबेला ERROR हो त्यो ERROR लेखेर त्यहि stop गर्ने।

Stack को top मा handle देख्न भने shift गर्ने handle भए Reduce गर्ने

Shift/reduce conflict → दोहो case मा S handle होइन but S+S handle हो so यो तिर reduce गर्दा नि हुन्छ S→S+S, फरक पर्दैन यो ques मा

Shift गर्दा input buffer मा भएको first symbol stack को top मा move गर्ने

Reduce गर्दा terminal symbol लाई non-terminal ले replace गर्ने rule अनुसार

accept हुन stack मा $ र start symbol मात्र बच्नु पर्छ र input buffer मा $ symbol मात्र

Example 2: Use the grammar, and perform shift reduce parsing.

$E \rightarrow E+T \mid T$

$T \rightarrow T*F \mid F$

$F \rightarrow (E) \mid id$

Input string: id+id*id

Solution:

Stack	Input Buffer	Parsing Action.
$	id+id*id$	Shift id
$id	+id*id$	Reduce by F→id
$F	+id*id$	Reduce by T→F
$T	+id*id$	Reduce by E→T
$E	+id*id$	Shift +
$E+	id*id$	Shift id
$E+id	*id$	Reduce by F→id
$E+F	*id$	Reduce by T→F
$E+T	*id$	Shift * (OR Reduce by E→T) CONFLICT
$E+T*	id$	Shift id
$E+T*id	$	Reduce by F→id
$E+T*F	$	Reduce by T→T*F
$E+T	$	Reduce by E→E+T
$E	$	Accept

we find possible ways to accept string in this case

T alone is handle whole E+T is also handle so, this is case of reduce/reduce conflict

we have production E→T so T is handle but if we reduce T by E it will be E+E but later E+E can't be reduced which is not in production and may lead to error so we did shift operation in this type of conflict case.

Practice more questions from text book

⊛ Conflicts in Shift-Reduce Parsing:

There are two kinds of shift-reduce conflicts:

exam मा आए example पनि गरेर देखाउने

1) **Shift/Reduce Conflict:** Here, the parser is not able to decide whether to shift or to reduce. (like in 6th step of example 1)

2) **Reduce/Reduce Conflict:** Here, the parser cannot decide which sentential form to use for reduction. (like in 9th step of example 2).

b) LR Parser:

shift reduce मा shift/reduce र reduce/reduce conflict आउँदा यो method use गर्दा conflict आउँदैन।

LR parsing is one type of bottom up parsing. It is used to parse large class of grammars. In the LR parsing, L stands for left-to-right scanning of the input. R stands for constructing a right most derivation in reverse. We will study SLR, LR(1) and LALR(1) here in this section.

LR Parsers: General Structure

The LR algorithm requires stack, input, output and parsing table. In all type of LR parsing, input, output, and stack are same but parsing table is different.

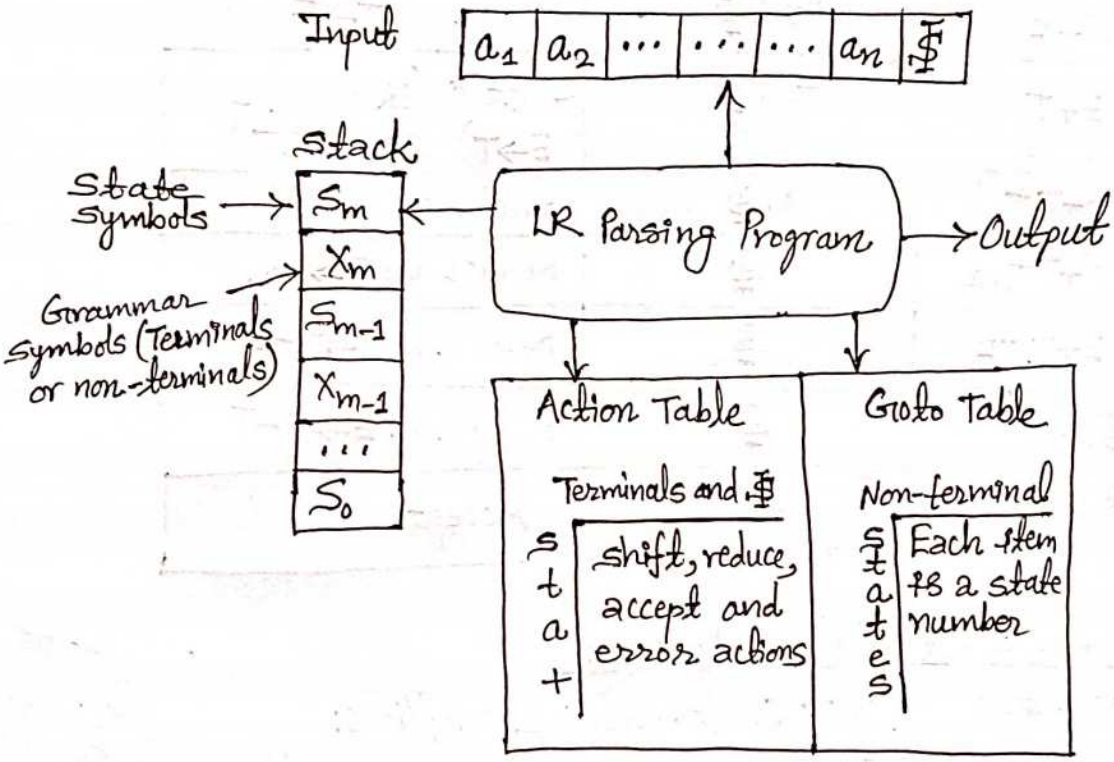


Fig: Block diagram of LR parser.

यो basic terminologies short note मा 5 marks को आउँछ exp. ई।

1) SLR (Simple LR Parser):

Basic terminologies used for LR parsing table:

↳Augmented grammar: If G is a grammar with start symbol S, then the augmented grammar G' of G is a grammar with a new start symbol S' and production $S' \rightarrow S$.

Example: the grammar,

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

same

It's augmented grammar is,

$E' \rightarrow E$
$E \rightarrow E+T \mid T$
$T \rightarrow T*F \mid F$
$F \rightarrow (E) \mid id$

starting symbol को dash gives starting symbol given grammar को सुरुमा भएको एसलाई augmented grammar भनिन्छ।

↳ **LR(0) Item:** An 'item' (LR(0) item) is a production rule that contains a dot (•) somewhere in the right side of the production. For example, the production $A \to \alpha A \beta$ has four items:

$A \to \bullet \alpha A \beta$
$A \to \alpha \bullet A \beta$
$A \to \alpha A \bullet \beta$
$A \to \alpha A \beta \bullet$

↔ कुनै production को right side मा कुन कुन ठाउँमा • राख्न सकिन्छ त्यो सबै possible outcome लाई LR(0) item भनिन्छ। • सबै ठाउँमा राख्न मिल्छ terminal, non-terminal symbol को मतलब नराख

A production $A \to \varepsilon$, generates only one item $A \to \bullet$.

↳ **Closure Operation:** If I is a set of items for a grammar G, then closure(I) is the set of LR(0) items constructed from I using the following rules:

→ Symbol like β which can be terminal or non-terminal

1. Initially, every LR(0) item in I is added to closure(I).
2. If $A \to \alpha \bullet B\beta$ in closure(I) and $B \to \gamma$ is a production rule of G then add $B \to \bullet\gamma$ in the closure(I) repeat until no more new LR(0) items added to closure(I).

Example: Consider the grammar:

$E \to E+T \mid T$
$T \to T*F \mid F$
$F \to (E) \mid id$

It's augmented grammar is;

$E' \to E$
$E \to E+T \mid T$
$T \to T*F \mid F$
$F \to (E) \mid id$

If $I = \{[E' \to \bullet E]\}$, then closure I contains the items,

$E' \to \bullet E$
$E \to \bullet E+T$
$E \to \bullet T$
$T \to \bullet T*F$
$T \to \bullet F$
$F \to \bullet (E)$
$F \to \bullet id$

अरु पनि लिन सक्थ्यो but example का लागि $E' \to E$ लिएको

↔ closure निकाल्दा • को पछाडि जुन symbol छ त्यसेल्ट लिन सक्ने OR त्यो बाट हामि कुन कुन production मा पुग्न सक्छै, सुरुमा • लेखेर त्यो सबै production लेख्दौं। Foreg we have $E' \to \bullet E$ initially. We have E after • so we write productions of E using dot at start as $\bullet E+T$ and $\bullet T$ again we have T which can produce again and so on.

↳ **Goto Operation:**

If I is a set of LR(0) items and X is a grammar symbol (terminal or non-terminal), then goto(I, X) is defined as follows:

If $A \to \alpha \bullet X\beta$ in I then every item in closure $(\{A \to aX \bullet \beta\})$ will be in goto(I, X).

↔ goto निकाल्दा सुरुमा • symbol, 1 step पछाडि सार्ने then त्यो • पछिको symbol को साथि जोड्दै गरि closure operation गर्ने त्यति हो।

Example:

Let, $I = \{E' \to \cdot E, E \to \cdot E+T, E \to \cdot T, T \to \cdot T*F, T \to \cdot F, F \to \cdot(E), F \to \cdot id\}$

Now,

$goto(I, E) = closure(\{[E' \to E^\cdot, E \to E^\cdot + T]\})$

$= \{E' \to E^\cdot, E \to E^\cdot + T\}$

$goto(I, T) = closure(\{[E \to T^\cdot, T \to T^\cdot * F]\})$

$= \{E \to T^\cdot, T \to T^\cdot * F\}$

$goto(I, F) = closure(\{[T \to F^\cdot]\})$

$= \{T \to F^\cdot\}$

$goto(I, ( ) = closure(\{[F \to (\cdot E)]\})$

$= \{F \to (\cdot E), E \to \cdot E+T, E \to \cdot T, T \to \cdot T*F, T \to \cdot F, F \to \cdot(E), F \to \cdot id\}$

$goto(I, id) = closure(\{[F \to id^\cdot]\})$

$= \{F \to id^\cdot\}$

Now we are finding goto of E, so • E produce गर्ने term हरु मात्र लिएर त्यो set को goto गर्दा। goto means shift • one step right then do closure

• T पछिका term मात्र हर्ने

$E' \to E^\cdot$ मा • पछि कुनै term हुँदैन so no closure or no other new production occur. $E \to E^\cdot + T$ मा • पछि + symbol हुँ so, terminal symbol को closure हुँदा non-terminal को मात्र so same term as closure of that

• पछि E हुँ so E को closure निकाल्न मिल्छ। means E बाट जुन जुन production पुग्न सक्दो त्यो सबै सुरुमा • लगेर

• पछि terminal non-terminal जे आए पनि सबको goto निकाल्न मिल्छ। $F \to \cdot(E)$ मा • पछि opening brace आयो so यसको goto

↳ Canonical LR(0) collection:

To construct canonical LR(0) collection of grammar we require augmented grammar, closure, and goto functions.

Algorithm:

1. Start
2. Augment the grammar by adding production $S' \to S$.
3. $C = \{closure(\{S' \to S\})\}$
4. Repeat the followings until no more set of LR(0) items can be added to C.

   for each I in C and each grammar symbol X
   if goto(I, X) is not empty and not in C
   add goto(I, X) to C.
5. Repeat step 4 until no new sets of items are added to C.
6. Stop.

यो algorithm solving process बुझ्न मात्र हो रटनु पर्दैन।

i.e, each LR(0) item को goto निकाल्नु पर्छ।

Example 1: Find canonical collection of LR(0) items of following grammar.

$C \to AB$
$A \to a$
$B \to a$

Solution:

The augmented grammar of given grammar is;

$C' \to C$
$C \to AB$
$A \to a$
$B \to a$

Next, We obtain the canonical collection of sets of LR(0) items as follows;

$I_0 = closure(\{C' \to \cdot C\}) = \{C' \to \cdot C, C \to \cdot AB, A \to \cdot a\}$

$I_1 = goto(I_0, C) = closure(C' \to C\cdot) = \{C' \to C\cdot\}$

$I_2 = goto(I_0, A) = closure(C \to A\cdot B) = \{C \to A\cdot B, B \to \cdot a\}$

$I_3 = goto(I_0, a) = closure(A \to a\cdot) = \{A \to a\cdot\}$

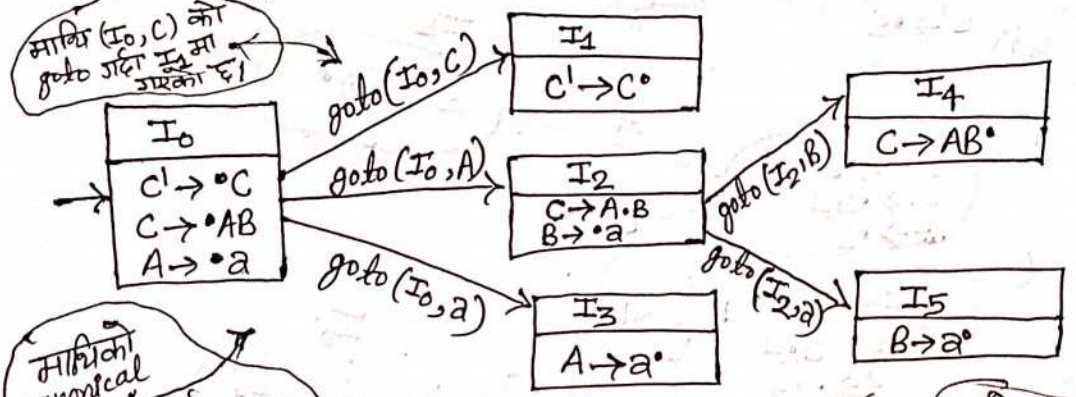
$I_4 = goto(I_2, B) = closure(C \to AB\cdot) = \{C \to AB\cdot\}$

$I_5 = goto(I_2, a) = closure(B \to a\cdot) = \{B \to a\cdot\}$

सुरुको state लाई हामिले I_0 मान्छौं। सुरुको state मा augmented grammar की first production को closure निकाल्छौं।

Now, I_0 मा • भाको symbol •C, •A, र •a छन्, so अब यो symbol हरुको goto निकाल्ने र नया states I_1, I_2, I_3 मा राख्ने

अब I_2 मा goto calculate गर्नेको नया symbol •B भयो so अब I_2 set मा भएका सबै •को goto निकाल्ने •B र •a को



Example 2: Find canonical collection of LR(0) items of following grammar

$S \to AA$
$A \to aA \mid b$

Solution:

The augmented grammar of given grammar is;

$S' \to S$
$S \to AA$
$A \to aA$
$A \to b$

Now we obtain the canonical collection of sets of LR(0) items as follows;

$I_0 = closure(\{S' \to \cdot S\}) = \{S' \to \cdot S, S \to \cdot AA, A \to \cdot aA, A \to \cdot b\}$

$I_1 = goto(\{I_0, S\}) = closure(\{S' \to S\cdot\}) = \{S' \to S\cdot\}$

$I_2 = goto(\{I_0, A\}) = closure(\{S \to A\cdot A\}) = \{S \to A\cdot A, A \to \cdot aA, A \to \cdot b\}$

$I_3 = goto(\{I_0, a\}) = closure(\{A \to a\cdot A\}) = \{A \to a\cdot A, A \to \cdot aA, A \to \cdot b\}$

$I_4 = goto(\{I_0, b\}) = closure(\{A \to b\cdot\}) = \{A \to b\cdot\}$

$I_5 = goto(\{I_2, A\}) = closure(\{S \to AA\cdot\}) = \{S \to AA\cdot\}$

(goto calculate गर्दा first state मा यदि assign गर्दा because यस्तो case हरु आउछ)

$I_3 = goto(\{I_2, a\}) = closure(\{A \to a\cdot A\}) = \{A \to a\cdot A, A \to \cdot aA, A \to \cdot b\}$

(This is same as I_3 state so no need to assign to new state I_6. Now, the transition goto (I_2, a) will go to I_3 as it is same to I_3)

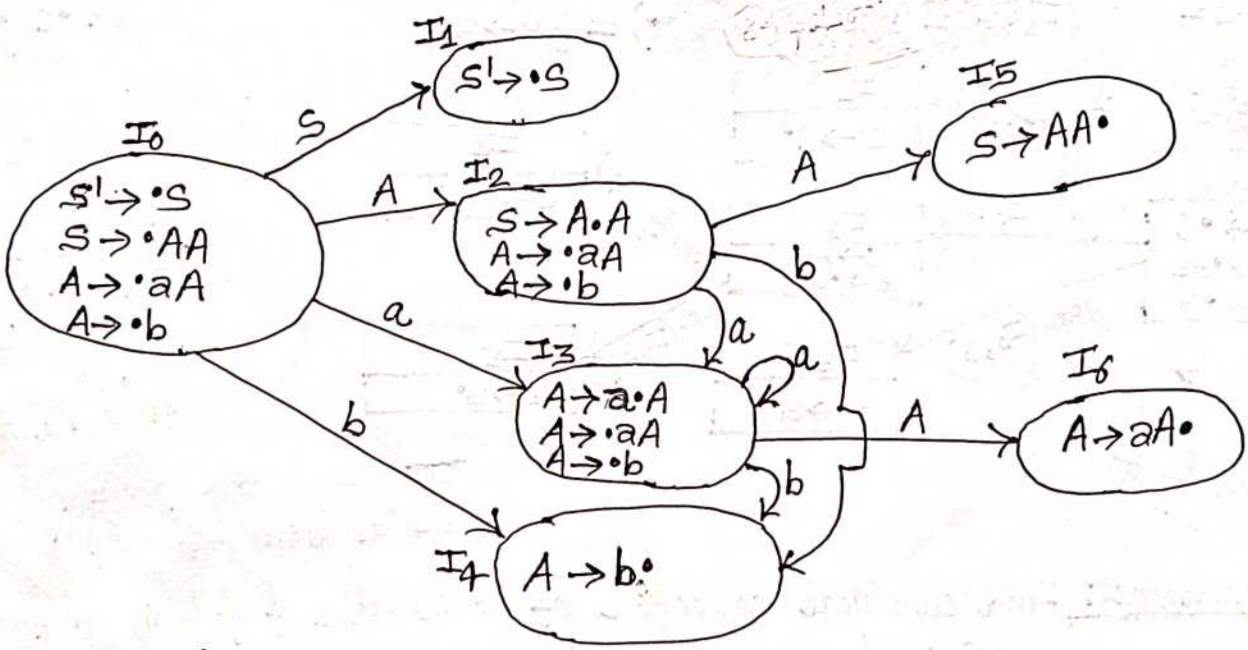
$I_4 = goto(\{I_2, b\}) = closure(\{A \to b\cdot\}) = \{A \to b\cdot\}$ (Same as I_4 so assigned to I_4 instead of new state)

$I_6 = goto(\{I_3, A\}) = closure(\{A \to aA\cdot\}) = \{A \to aA\cdot\}$

$I_3 = goto(\{I_3, a\}) = closure(\{A \to a\cdot A\}) = \{A \to a\cdot A, A \to \cdot aA, A \to \cdot b\}$ (Same as I_3)

$I_4 = goto(\{I_3, b\}) = closure(\{A \to b\cdot\}) = \{A \to b\cdot\}$ (Same as I_4)

Drawing DFA: For DFA of above cannonical LR(0) collection we have 7 states I_0 to I_6 as follows:



⊛ Constructing SLR Parsing Tables:

Algorithm: (just to understand)

1. Construct the canonical collection of sets of LR(0) items for G'.
   $C \leftarrow \{I_0, I_1, \ldots, I_n\}$
2. Create the parsing action table as follows
   - If $A \to \alpha\cdot a\beta$ is in I_i and $goto(I_i, a) = I_j$ then set action $[i, a]$ = shift j.
   - If $A \to \alpha\cdot$ is in I_i, then set action $[i, a]$ to "reduce $A \to \alpha$" for all 'a' in FOLLOW(A). where, $A \neq S'$.
   - If $S' \to S\cdot$ is in I_i, then action $[i, \$]$ = accept.
   - If any conflicting actions generated by these rules, the grammar is not SLR(1).

3. Create the parsing goto table.
   - for all non-terminals A, if goto $(I_i, A) = I_j$ then goto $[i, A] = j$
4. All entries not defined by (2) and (3) are errors.
5. Initial state of the parser contains $S' \rightarrow \cdot S$.

Example 1: Construct SLR parsing table of following grammar.

$C \rightarrow AB$
$A \rightarrow a$
$B \rightarrow a$

Solution:

The augmented grammar of given grammar is;

$C' \rightarrow C$
$C \rightarrow AB$
$A \rightarrow a$
$B \rightarrow a$

These process are same as we already did before in examples of canonical collection of LR(0) items all same

Next, we obtain the canonical collection of sets of LR(0) items as follows,

$I_0 = \text{closure}(\{C' \rightarrow \cdot C\}) = \{C' \rightarrow \cdot C, C \rightarrow \cdot AB, A \rightarrow \cdot a\}$

$I_1 = \text{goto}(I_0, C) = \text{closure}(C' \rightarrow C\cdot) = \{C' \rightarrow C\cdot\}$

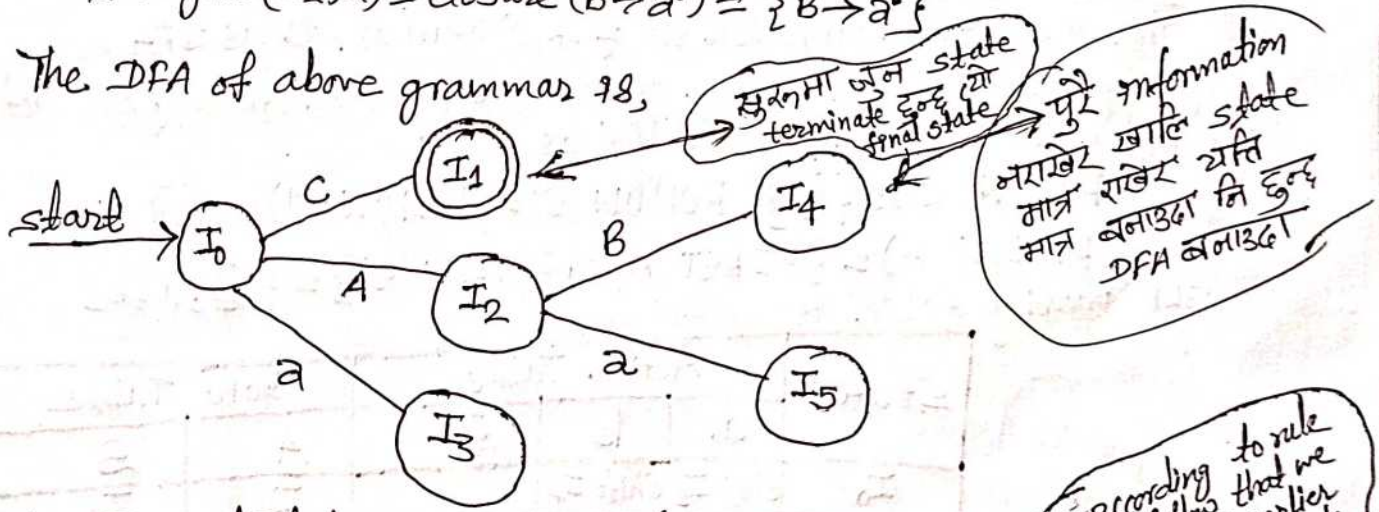
$I_2 = \text{goto}(I_0, A) = \text{closure}(C \rightarrow A \cdot B) = \{C \rightarrow A \cdot B, B \rightarrow \cdot a\}$

$I_3 = \text{goto}(I_0, a) = \text{closure}(A \rightarrow a\cdot) = \{A \rightarrow a\cdot\}$

$I_4 = \text{goto}(I_2, B) = \text{closure}(C \rightarrow AB\cdot) = \{C \rightarrow AB\cdot\}$

$I_5 = \text{goto}(I_2, a) = \text{closure}(B \rightarrow a\cdot) = \{B \rightarrow a\cdot\}$

The DFA of above grammar is,



Now we calculate FOLLOW function as;

according to rule of follow that we studied earlier have a look

$\text{FOLLOW}(C') = \{\$\}$ $\quad \text{FOLLOW}(C) = \{\text{FOLLOW}(C')\} = \{\$\}$

grammar मा rightside C' भएको हुदा यहि देख so empty only $ symbol

$\text{FOLLOW}(A) = \{\text{FIRST}(B) \cup a\} = \{a\}$

$\text{FOLLOW}(B) = \{\text{FOLLOW}(C)\} = \{\$\}$

Now finally we construct SLR parsing table as below:

States	Action Table		Goto Table		
	a	$	C	A	B
I_0	Shift I_3		I_1	I_2	
I_1		Accept			
I_2	Shift I_5				I_4
I_3	Reduce R_2				
I_4		Reduce R_1			
I_5		Reduce R_3			

(1) Action table मा terminals a र $, GoTO table मा non-terminals C, A, B

(2) $I_0, I_1 \ldots I_n$ को set हेनमा भएको production हेर्ने mainly 3 case हुन्छन् /
1) $A \to \alpha \cdot a\beta$ form (i.e, • पछि terminal) आए shift गर्ने /
2) $A \to \alpha \cdot$ form आए (last मा • भाको) र augmented grammar को 1st production बाहेक अरु reduce $A \to \alpha$ गर्ने i.e, FOLLOW(A) हेर्ने /
3) Augmented grammar को first production आए Accept गर्ने /
यो 3 case मध्ये कुनै पनि नभए हामि neglect गरेर table मा राख्दैनौं

(3) सुरुमा I_0 को set हेर्यौं / $C \to \cdot C$ र $C \to \cdot AB$ ले कुनै पनि 3 case satisfy गरेन so we neglect them / $A \to \cdot a$ first case सँग match गर्‍यो / So, I_0 मा a को तल shift हुन्छ / DFA मा I_0 मा a आउँदा I_3 मा जान्छ so we write Shift I_3
Now we are in I_1 set, we have $C' \to C \cdot$ which satisfies 3rd case so, $ को लागि accept गर्ने according to rule/algorithm, and so on.....

(4) state हेर्ने non-terminal आउँदा कता जाको छ त्यो i.e, goto

Short मा shift लाई S, Accept लाई Acc, र Reduce लाई R लेखिन्छ

→ 3rd Reduce वाला case आए, जसले produce गरेको छ त्यसको FOLLOW निकाल्ने / त्यसपछि FOLLOW मा भएको symbol को तल Reduce लेख्ने /

Example 2: Construct the SLR parsing table for the grammar.

$S \to AA$
$A \to aA \mid b$

Solution:

The augment and cannonical set of LR(0) item as well as DFA is same as we solved before section in example 2, so we directly construct table here calculating FOLLOW as below:

$FOLLOW(S') = \{\$\}$ $FOLLOW(S) = \{FOLLOW(S')\} = \{\$\}$

$FOLLOW(A) = \{FIRST(A) \cup FOLLOW(S)\} = \{\$, a, b\}$

SLR parsing table is as follows:

States	Action Table			Goto Table	
	a	b	$	A	S
I_0	Shift I_3	Shift I_4		I_2	I_1
I_1			Accept		
I_2	Shift I_3	Shift I_4		I_5	
I_3	Shift I_3	Shift I_4		I_6	
I_4	Reduce I_3	Reduce I_3	Reduce I_3		
I_5			Reduce I_1		
I_6	Reduce I_2	Reduce I_2	Reduce I_2		

we can practice more examples from kec book's page no. 46 onwards

table बनाउँदा हरेक cell मा more than one action आए जस्तै shift र shift, shift र reduce etc. possibility भएको बेला parsable हुने grammar यसलाई ambiguity in SLR भनिन्छ /

4) LR(1) Grammars:

→ 2nd type of LR parser (also called General LR) after shift-reduce parsing. यसमा canonical set of LR(1) निकालिन्छ instead of LR(0) अरु table draw गर्नु, goto निकाल्नु, closure निकाल्नु सबै same as we did in shift-reduce.

LR(1) parsing uses look-ahead to avoid unnecessary conflicts in parsing table.

LR(1) item = LR(0) item + look-ahead.

LR(1) item भनेको LR(0) जस्तै हो अप यसमा look-ahead भन्नि हुन्छ।

LR(0) item	LR(1) item
$[A \to \alpha \cdot \beta]$	$[A \to \alpha \cdot \beta, a]$

LR(0) item को form को हुन्छ

LR(1) item को form को हुन्छ where a is assumed look-ahead symbol.

Example 1: Construct LR(1) parsing table of following grammar,

$S \to AA$
$A \to aA$
$A \to b$

Solution: The augmented grammar of given grammar is;

$S' \to S$
$S \to AA$
$A \to aA$
$A \to b$

The canonical collection of LR(1) items of augmented grammar is:

$I_0 = \text{Closure}(S' \to \cdot S) = \{S' \to \cdot S, \$$
$S \to \cdot AA, \$$
$A \to \cdot aA, a/b$
$A \to \cdot b, a/b\}$

same as LR(0) item. comma(,) पछिको look-ahead मात्र फरक यसमा

सुरुको production मा look-ahead $ राख्छौं अनि यसलाई rule अनुसार $A \to [\alpha \cdot B\beta, a]$ सँग compare गर्दै dot पछिको एउटा non-terminal symbol छोडेर बाँकि रहेको string को FIRST निकाल्छौं, त्यो value 2nd production को look-ahead value हुन्छ and so on...
For e.g. $[S' \to \cdot S, \$]$ compared with $[A \to \alpha \cdot B\beta, a]$, now $FIRST(\$) = \{\$\}$ which is look-ahead of $S \to \cdot AA$

• पछिको एउटा symbol छोडि बाँकि को FIRST

Rule for look ahead symbol
If $A \to [\alpha \cdot B\beta, a] \in$ closure(I) then, add the item $[B \to \cdot\gamma, b]$ to I if not already in I. where, $b \in FIRST(\beta a)$

similarly $A \to \cdot aA$ production is given by $S \to \cdot AA, \$$, so, $FIRST(A\$) = FIRST(A) = \{a, b\}$. Hence, look-ahead is a/b.
similarly $A \to \cdot b$ production पनि $S \to \cdot AA, \$$ को गर्दा आएको हो so, same $FIRST(A) = \{a, b\}$

goto गर्दा • पछाडि भएको rule को form मा हेर्ने so दायाँ look-ahed नै आया calculate नगरि माथिकै राख्ने

$I_1 = \text{Goto}(I_0, S) = \text{closure}(S' \to S^\cdot, \$) = \{S' \to S^\cdot, \$\}$

$I_2 = \text{Goto}(I_0, A) = \text{closure}(S \to A \cdot A, \$) = \{S \to A \cdot A, \$$ (copy)
$A \to \cdot aA, \$$
$A \to \cdot b, \$\}$

यो production $S \to A \cdot A, \$$ ले गर्दा आको so $FIRST(\$) = \$$ is look-ahead by rule similarly this.

$I_3 = \text{Goto}(I_0, a) = \text{closure}(A \to a \cdot A, a/b) = \{A \to a \cdot A, a/b$
$A \to \cdot aA, a/b$
$A \to \cdot b, a/b\}$

β absent भए माथि भने झै look-ahead नै पनि look-ahead new calculate गर्नु पर्दैन

$I_4 = \text{Goto}(I_0, b) = \text{closure}(A \to b^\bullet, a/b) = \{A \to b^\bullet, a/b\}$

$I_5 = \text{Goto}(I_2, A) = \text{closure}(S \to AA^\bullet, \$) = \{S \to AA^\bullet, \$\}$

$I_6 = \text{Goto}(I_2, a) = \text{closure}(A \to a^\bullet A, \$) = \{A \to a^\bullet A, \$$
$A \to {}^\bullet aA, \$$
$A \to {}^\bullet b, \$\}$

β absent here so same $, $ in look-ahead as before

$I_7 = \text{Goto}(I_2, b) = \text{closure}(A \to b^\bullet, \$) = \{A \to b^\bullet, \$\}$

$I_8 = \text{Goto}(I_3, A) = \text{closure}(A \to aA^\bullet, a/b) = \{A \to aA^\bullet, a/b\}$

$\text{Goto}(I_3, a) = \text{closure}(A \to a^\bullet A, a/b) = \{A \to a^\bullet A, a/b$
$A \to {}^\bullet aA, a/b$
$A \to {}^\bullet b, a/b\}$ same as I_3

can be assigned to I_3 or left without assigned but understand Goto$(I_3, a) = I_3$

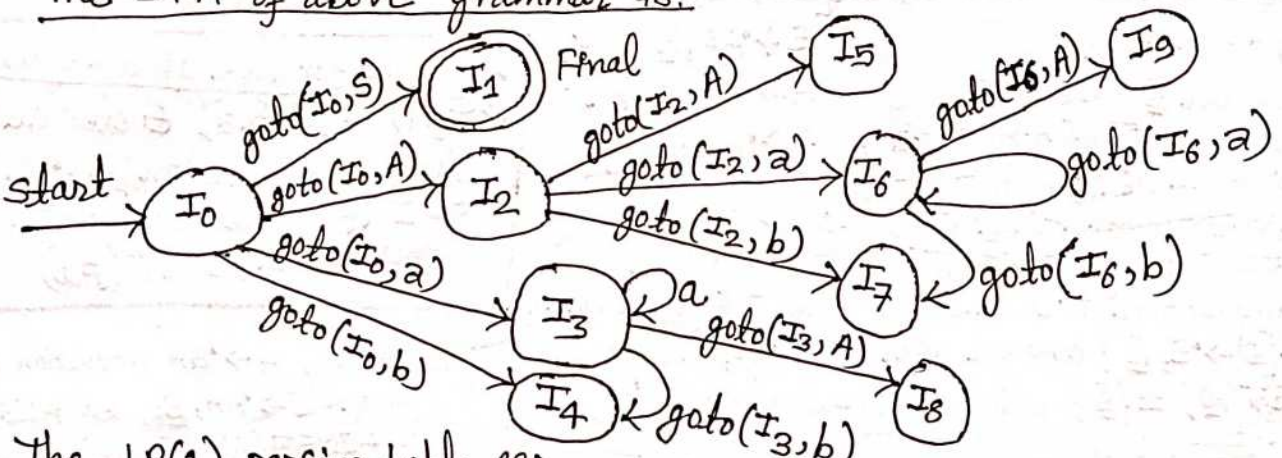
$\text{Goto}(I_3, b) = \text{closure}(A \to b^\bullet, a/b)$ same as I_4.

$I_9 = \text{Goto}(I_6, A) = \text{closure}(A \to aA^\bullet, \$) = \{A \to aA^\bullet, \$\}$

$\text{Goto}(I_6, a) = \text{closure}(A \to a^\bullet A, \$)$ same as I_6.

$\text{Goto}(I_6, b) = \text{closure}(A \to b^\bullet, \$)$ same as I_7.

The DFA of above grammar is:



The LR(1) parsing table is:

States	Action table			Goto Table	
	a	b	$	S	A
0	Shift I_3	Shift I_4		I_1	I_2
1			Accept		
2	Shift I_6	Shift I_7			I_5
3	Shift I_3	Shift I_4			I_8
4	Reduce I_3	Reduce I_3			
5			Reduce I_1		
6	Shift I_6	Shift I_7			I_9
7			Reduce I_3		
8	Reduce I_2	Reduce I_2			
9			Reduce I_2		

iii) LALR(1) Grammars:

everything same as LR(1) only difference here is we combine states having same productions, but can have different look-ahead symbol.

Example1: Construct LALR parsing table for following grammar,

$S \to L=R$

= is terminal symbol and L=R is one single string. Only next string when seperated by |

$S \to R$
$L \to *R$
$L \to id$
$R \to L$

Solution:

The augmented grammar of above grammar is,

$S' \to S$
$S \to L=R$
$S \to R$
$L \to *R$
$L \to id$
$R \to L$

At first we find the canonical collection of LR(1) items of the given augmented grammar as;

$I_0 = closure(S' \to \cdot S, \$)$
$= \{ S' \to \cdot S, \$$
$S \to \cdot L=R, \$$
$S \to \cdot R, \$$
$L \to \cdot *R, \$$
$L \to \cdot id, =$
$R \to \cdot L, \$ \}$

$I_1 = closure(goto(I_0, S))$
$= closure(S' \to S \cdot, \$)$
$= \{ S' \to S \cdot, \$$
$R \to L \cdot, \$ \}$

$I_2 = closure(goto(I_0, L))$
$= closure(\{S \to L \cdot = R, \$), (R \to L \cdot, \$))$
$= \{ S \to L \cdot = R, \$ \}$

$I_3 = closure(goto(I_0, R))$
$= closure(S \to R \cdot, \$)$
$= \{ S \to R \cdot, \$ \}$

$I_4 = closure(goto(I_0, *))$
$= closure(L \to * \cdot R, =)$
$= \{ (L \to * \cdot R, =), (R \to \cdot L, =), (L \to \cdot *R, =), (L \to \cdot id, =) \}$

$I_5 = closure(goto(I_0, id))$
$= closure(L \to id \cdot, =)$
$= \{ L \to id \cdot, = \}$

$I_6 = closure(goto(I_2, =))$
$= closure(S \to L= \cdot R, \$)$
$= \{ S \to L= \cdot R, \$$
$R \to \cdot L, \$$
$L \to \cdot *R, \$$
$L \to \cdot id, \$ \}$

$I_7 = closure(goto(I_4, R))$
$= closure(L \to *R \cdot, =)$
$= \{ L \to *R \cdot, = \}$

$I_8 = closure(goto(I_4, L))$
$= closure(R \to L \cdot, =)$
$= \{ R \to L \cdot, = \}$

$I_{12} = closure(goto(I_6, id))$
$= closure(L \to id \cdot, \$)$
$= \{ L \to id \cdot, \$ \}$

$I_{13} = closure(goto(I_{11}, R))$
$= \{ L \to *R \cdot, \$ \}$

यहाँ 12 र 13, 11 पनि last मा हुने भएता last मा गर्ने घुटेको हुँदा so यता राखेको

$I_9 = closure(goto(I_6, R))$
$= closure(S \to L = R^\bullet, \$)$
$= \{S \to L = R^\bullet, \$\}$

$I_{10} = closure(goto(I_6, L))$
$= \{R \to L^\bullet, \$\}$

$I_{11} = closure(goto(I_6, *))$
$= closure(L \to *^\bullet R, \$)$
$= \{L \to *^\bullet R, \$$
$R \to {}^\bullet L, \$$
$L \to {}^\bullet *R, \$$
$L \to {}^\bullet id, \$\}$

यो सम्म सब same हो as before अब यो combine गर्ने मात्र different

Now we combine states as follows:

Combine गर्दा दुईवटै state मा same no. of productions हुने पर्यो र core productions पनि same हुने पर्छ सबै look-ahead symbol छोडेर बाकी सबैको लाई core production भनिन्छ।

Combine state 4 and 11 as:

$I_4: \{(L \to *^\bullet R, =), (R \to {}^\bullet L, =), (L \to {}^\bullet *R, =), (L \to {}^\bullet id, =)\}$
$I_{11}: \{(L \to *^\bullet R, \$), (R \to {}^\bullet L, \$), (L \to {}^\bullet *R, \$), (L \to {}^\bullet id, \$)\}$
$I_{4,11}: \{(L \to *^\bullet R, =/\$), (R \to {}^\bullet L, =/\$), (L \to {}^\bullet *R, =/\$), (L \to {}^\bullet id, =/\$)\}$

Combine गरेको दुईवटै state को look-ahead symbol slash गरी लेखेको

Combine state 5 and 12 as;

$I_5: \{L \to id^\bullet, =\}$
$I_{12}: \{L \to id^\bullet, \$\}$
$I_{5,12}: \{L \to id^\bullet, =/\$\}$

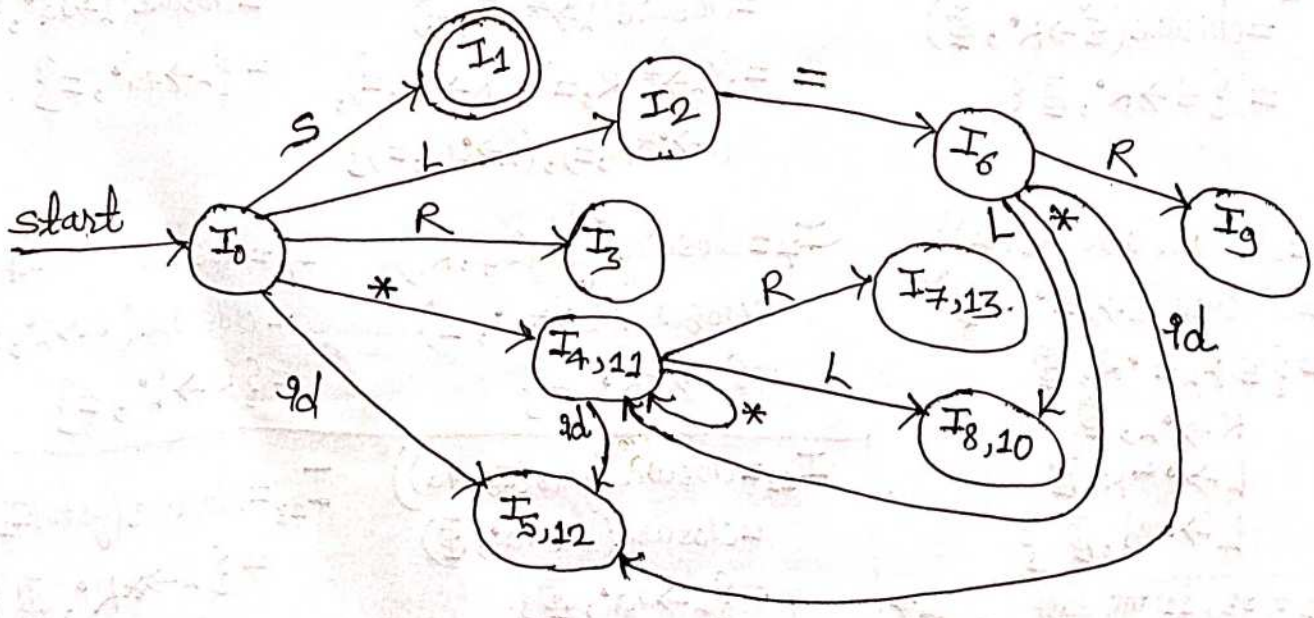
Combine state 7 and 13 as;

$I_7: \{L \to *R^\bullet, =\}$
$I_{13}: \{L \to *R^\bullet, \$\}$
$I_{7,13}: \{L \to *R^\bullet, =/\$\}$

Combine state 8 and 10 as;

$I_8: \{R \to L^\bullet, =\}$
$I_{10}: \{R \to L^\bullet, \$\}$
$I_{8,10}: \{R \to L^\bullet, =/\$\}$

Now the DFA of LALR parsing is:



The LALR parsing table is:

States	Action Table				Goto Table		
	id	*	=	$	S	L	R
0	Shift I_5	Shift I_4			I_1	I_2	I_3
1				Accept			
2			Shift I_6	Reduce I_5			
3				Reduce I_2			
4	Shift I_5	Shift I_4				I_8	I_9
5			Reduce I_4	Reduce I_4			
6	Shift I_{12}	Shift I_{11}				I_{10}	I_9
7			Reduce I_3	Reduce I_3			
8			Reduce I_5	Reduce I_5			
9				Reduce I_1			

table also same method as before ↔ यो I_4 भनेको अब $I_{4,11}$ हो combine गरेको भएर similarly others which are combined.

⊛ Kernel and Non-Kernel Items:

Kernel item includes the initial items, $S' \to .S$ and all items whose dot are not at the left end. Similarly non-kernel items are those items which have their dots at the left end except $S' \to .S$

Example: Find the kernel and non-kernel items of following grammar,

$C \to AB$
$A \to a$
$B \to a$

Solution:

The augmented grammar of given grammar is,

$C' \to C$
$C \to AB$
$A \to a$
$B \to a$

Now, we obtain the canonical collection of sets of LR(0) items as follows,

$I_0 = \text{closure}(\{C' \to \cdot C\}) = \{C' \to \cdot C, C \to \cdot AB, A \to \cdot a\}$

$I_1 = \text{goto}(I_0, C) = \text{closure}(C' \to C\cdot) = \{C' \to C\cdot\}$

$I_2 = \text{goto}(I_0, A) = \text{closure}(C \to A\cdot B) = \{C \to A\cdot B, B \to \cdot a\}$

$I_3 = \text{goto}(I_0, a) = \text{closure}(A \to a\cdot) = \{A \to a\cdot\}$

$I_4 = goto(I_2, B) = closure(C \to AB^\bullet) = \{C \to AB^\bullet\}$

$I_5 = goto(I_2, a) = closure(B \to a^\bullet) = \{B \to a^\bullet\}$

List of kernel and non-kernel items are listed below:

States	Kernel Items	Non-kernel items
I_0	$C' \to {}^\bullet C$	$C \to {}^\bullet AB$ $A \to {}^\bullet a$
I_1	$C' \to C^\bullet$	
I_2	$C \to A^\bullet B$	$B \to {}^\bullet a$
I_3	$A \to a^\bullet$	
I_4	$C \to AB^\bullet$	
I_5	$B \to a^\bullet$	

Augmented grammar को सुरुको production S सुरुमा dot (•) भएको सबै kernel item. सुरुको production $C' \to {}^\bullet C$ बाहेक सुरुमा dot (•) भएको सबै non-kernel item

⊛ Top down Parsing vs. Bottom up Parsing:

S.N.	Top down parsing	Bottom up parsing
1.	It is a parsing strategy that first looks at the highest level of the parse tree and works down the parse tree by using the rules of grammar.	It is a parsing strategy that first looks at the lowest level of the parse tree and works up the parse tree by using the rules of grammar.
2.	This parsing technique uses left most derivation.	This parsing technique uses right most derivation.
3.	Its main decision is to select what production rule to use in order to construct the string.	Its main decision is to select when to use a production rule to reduce the string to get the starting symbol.
4.	Error detection is easy	Error detection is difficult.
5.	Parsing table size is small.	Parsing table size is bigger.
6.	Less Power	High Power.

Semantic Analysis

यो बाट 1 short question र 5 marks को लागि

Introduction: Semantic Analysis is the third phase of compiler which provides meaning to its constructs, like tokens and syntax structure.

CFG + semantic rules = Syntax Directed Definitions.

Examples of Semantic Errors:

Example1: Use of a non-initalized variable.

```
int i;
i++; //the variable i is not initialized.
```

Example2: Type incompatibility

```
int a="hello"; //the types String and int are not compatible.
```

Example3: Errors in expressions

```
char s='A';
int a=15-s; //the '-' operator does not support type char.
```

Example4: Array index out of range.

```
int a[10];
a[12]=25; //12 is not legal index, we have index 0 to 9
          for array of size 10.
```

Example5: Unknown references

```
int a;
printf("%d", a); //a is not initialized.
```

Type Checking: Compiler must check that the source program follows both the syntatic and semantic conventions of the source language. Type checking is the process of checking the data type of different variables. The design of a type checker for a language is based on information about the syntatic construct in the language, the notation of type, and the rules for assigning types to the language constructs.

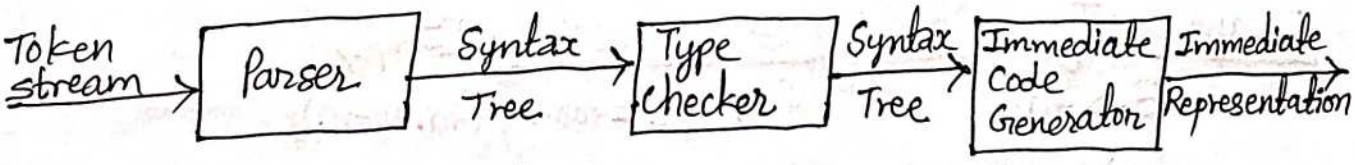


Fig: Position of Type Checker.

⊛ **Type Systems:** The collection of different data types and their associated rules to assign types to programming language constructs is known as type systems. It is an informal type system rules, for example "if both operands of addition are of type integer, then the result is of type integer." A type checker implements type system.

⊛ **Type Expressions:** The type of a language construct will be denoted by a "type expression". A type expression is either a basic type or is formed by applying an operator called a type constructor to other type expressions. The sets of basic types and constructors depend on the language to be checked.

Constructors include: ← just understand only

- **Arrays:** If T is a type expression then array(I,T) is a type expression denoting the type of an array with elements of type T and index set I. Example: array(0...99, int).
- **Products:** If T1 and T2 are type expressions, then their Cartesian product T1 × T2 is a type expression. Example: int × int.

Records: The record type constructor will be applied to a tuple formed from field names and field types.

- **Pointers:** If T is a type expression, then pointer(T) is a type expression denoting the type "pointer to an object of type T." For example, var p: ↑ row declares variable p have type pointer(row).

Functions: A function in programming languages maps a domain type D to a range type R. The type of such function is denoted by the type expression D→R. Example: int→int represents the type of a function which takes an int value as parameter, and its return type is also int.

Example: Type Checking of Expressions: [Imp]

E → id	{E.type = lookup(id.entry)}
E → charliteral	{E.type = char}
E → intliteral	{E.type = int}

$E \rightarrow E1 + E2$	{E.type = (E1.type == E2.type) ? E1.type : type_error}
$E \rightarrow E1 \uparrow$	{E.type = (E1.type == pointer(t)) ? t : type_error}
$E \rightarrow E1 [E2]$	{E.type = (E2.type == int and E1.type == array(s,t)) ? t : type_error}
$S \rightarrow id = E$	{S.type = (id.type == E.type) ? void : type_error}

(This bracket denotes index of array)

$S \rightarrow$ if E then S1	{S.type = (E.type == boolean) ? S1.type : type_error}
$S \rightarrow$ while E do S1	{S.type = (E.type == boolean) ? S1.type : type_error}
$S \rightarrow S1 ; S2$	{S.type = (S1.type == void and S2.type == void) ? void : type_error}

⊛Static vs. Dynamic Type Checking: [Imp]

Static Type Checking	Dynamic Type Checking
The type checking at compilation time is known as static type checking.	The type checking at runtime is known as dynamic type checking.
A language is statically-typed if the type of variable is known at compile time.	A language is strongly-typed, if every program it's compiler accepts will execute without type errors.
It includes languages such as C, C++, C#, Java, FORTRAN, Pascal etc.	It includes languages such as JavaScript, LISP, PHP, Python, Ruby etc.

Typical examples of static checking are:
→ Type checks
→ Flow-of-control checks
→ Uniqueness checks
→ Name-related checks
	Example: array out of bounds as below;
	`int a[10];`
	`for(int i=0; i<20; i++)`
	`a[i]=i;`

It is the process of reducing possibilities for bugs in programs and then checking that parts of program have been connected in a consistent way.	It is the process of verifying the type safety of a program at runtime.

⑧. Type Casting vs. Type Conversion:

Type Casting	Type Conversion (Coercion)
In type casting, a data type is converted into another data type by a programmer using casting operator.	In type conversion, a data type is converted into another data type by a compiler.
Type casting can be applied to compatible data types as well as incompatible data types.	Type conversion can only be applied to compatible data types.
In type casting, casting operator is needed in order to cast the data type to another data type.	In type conversion there is no need for a casting operator.
In type casting, the destination data type may be smaller than the source data type, when converting the data type to another data type.	In type conversion, the destination data type can't be smaller than source data type.
Type casting takes place during the program design by programmers.	Type conversion is done at the compile time.

⊛Syntax-Directed Translation (STD):

SDD मतलब describe गरेको आए यसको defn र SDD, SDTS short मा describe गर्ने

Syntax-Directed Translation (SDT) refers to a method of compiler implementation where the source language translation is completely driven by the parser. Almost all modern compilers are syntax-directed. The general approach to Syntax-Directed Translation is to construct a parse tree or syntax tree and compute the values of attributes at the nodes of the tree by visiting them in same order. There are two ways to represent semantic rules associated with grammar symbols.

→ Syntax-Directed Definitions (SDD).
→ Syntax-Directed Translation Schemes (SDTS).

explain this with suitable example गरेर normally. 80 अंक explain मा 1,1 example भएमा पुग्छ।

1) Syntax-Directed Definitions (SDD): [Imp]

A syntax-directed definition (SDD) is a context-free grammar together with attributes and rules. Attributes are associated with grammar symbols and rules are associated with productions. A SDD is a generalization of a context-free grammar in which each grammar symbol is associated with a set of attributes.

Example: The syntax directed definition for a simple desk calculator.

Production	Semantic Rules
L → E return	Print (E.val)
E → E1 + T	E.val = E1.val + T.val
E → T	E.val = T.val
T → T1 * F	T.val = T1.val * F.val
T → F	T.val = F.val
F → digit	F.val = digit.lexval

any variable that does not produce further

2) Syntax-Directed Translation Schemes (SDTS): [Imp]

SDTS embeds program fragments called semantic actions within production bodies. The position of semantic action in a production body determines the order in which the action is executed. It is used to evaluate the order of semantic rules.

Syntax, $A \rightarrow \{\ldots\} X \{\ldots\} Y \{\ldots\}$

where, within the curly brackets we define semantic actions.

Example: A simple translation scheme that converts infix expressions to the corresponding postfix expressions.

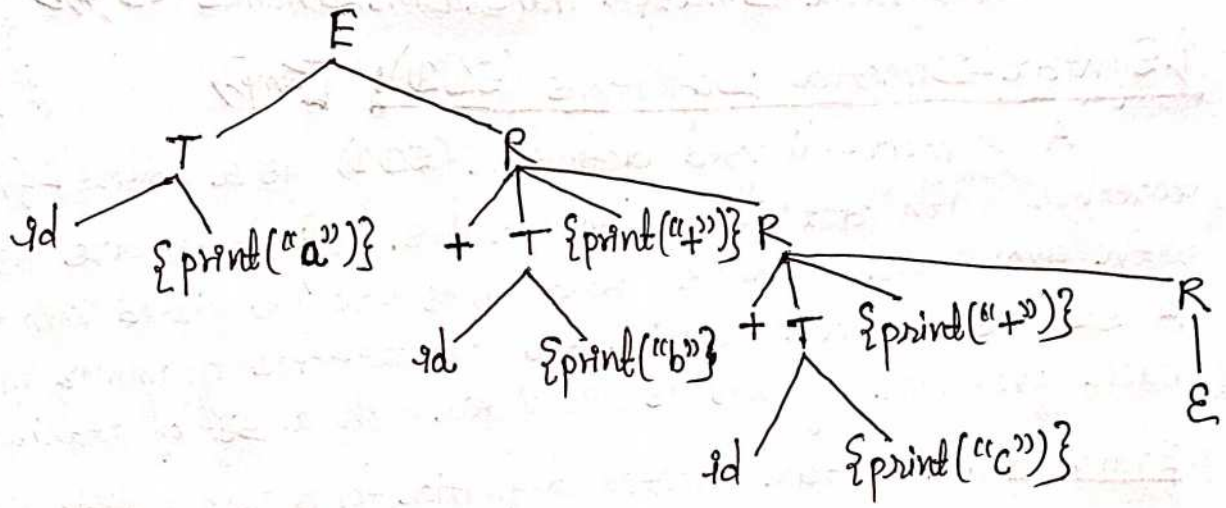
$E \rightarrow TR$

$R \rightarrow +T \{print("+")\} R_1$

$R \rightarrow \epsilon$

$T \rightarrow id \{print(id.name)\}$

Infix expression (a+b+c) ⟶ postfix expression (ab+c+).



⊛. ATTRIBUTE TYPES:

1) Synthesized Attribute (↑): If the value of the attribute only depends upon it's children then it is synthesized attribute. Simply we can also say that the attributes of a node that are derived from it's children nodes are called synthesized attributes. Let we have $S \rightarrow ABC$ as our production, now if S is taking values from it's child nodes (A, B, C) then it is said to be a synthesized attribute.

Example for Synthesized Attributes:

Production	Semantic Rules
L→E return	print (E.val)
E→E1+T	E.val = E1.val + T.val
E→T	E.val = T.val
T→T1*F	T.val = T1.val * F.val
F→digit	F.val = digit.lexval

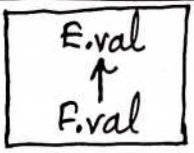
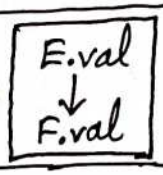
Same example as SDD

2) **Inherited Attribute (→, ↓):** A node in which attributes are derived from the parent or siblings of node is called inherited attribute of that node. If the value of the attribute depends upon it's parent or siblings then it is inherited attribute. Let we have production as $S \rightarrow ABC$, now if 'A' gets values from S, B and C, similarly if B can take values from S, A, C, likewise C can take values from S, A, and B.

Example for Inherited Attributes:

Production	Semantic Rules
D → TL	L.in = T.type
T → int	T.type = integer
T → real	T.type = real
L → L_1, id	L_1.in = L.in; addtype (id.entry, L.in)
L → id	addtype (id.entry, L.in).

⊛. Synthesized attributes vs. Inherited attributes:

Synthesized attribute	Inherited attributes.
Attributes of a node that are derived from its children nodes are called synthesized attributes.	Attributes which are derived from the parent or siblings of node are called inherited attribute.
The production must have non-terminal as its head.	The production must have non-terminal as a symbol in its body.
It can be evaluated during a single bottom-up traversal of parse tree.	It can be evaluated during a single top-down and sideways traversal of parse tree.
Synthesized attributes can be contained by both the terminals and non-terminals.	Inherited attributes can be only contained by non-terminals.
Example: E → F, E.val = F.val 	Example: E → F, E.val = F.val 

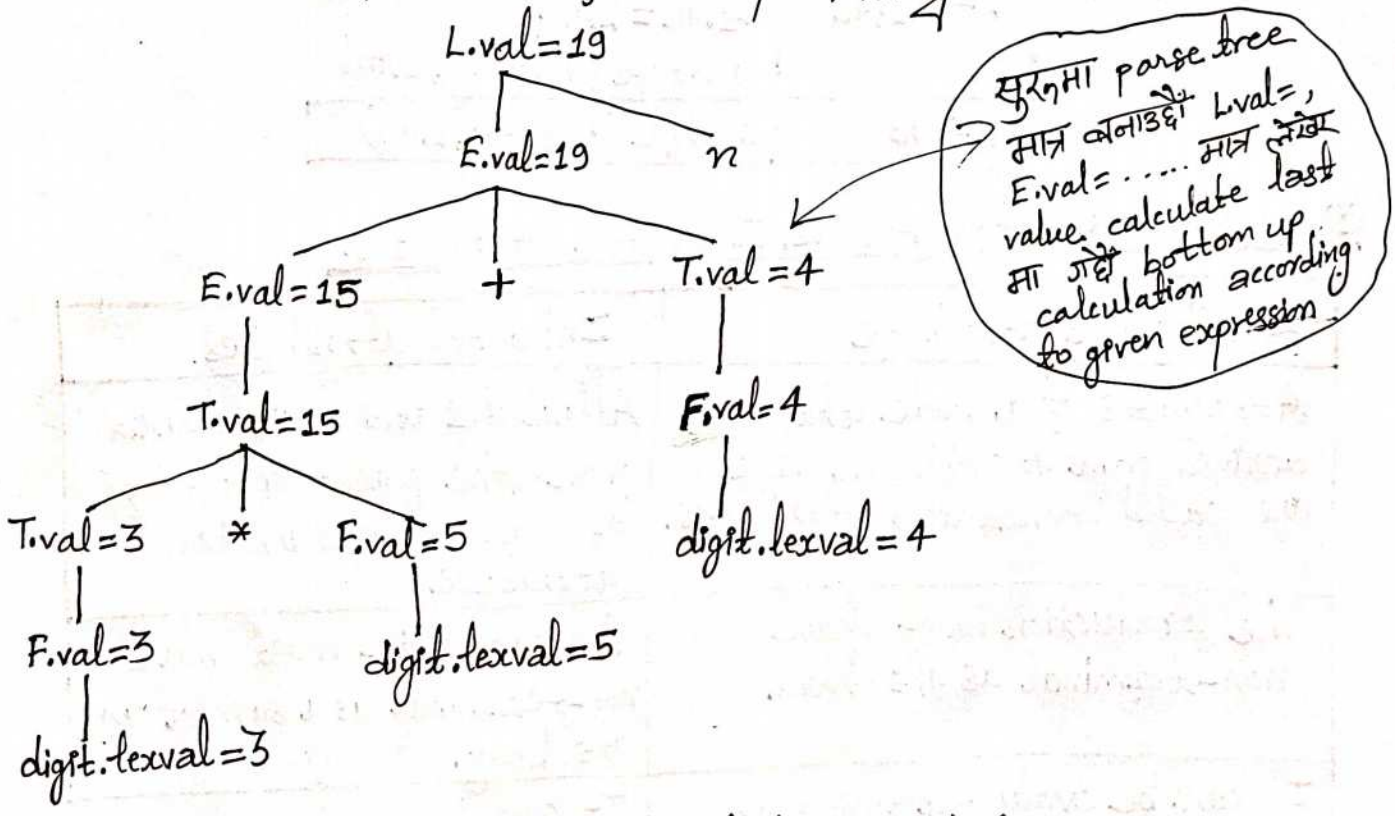
⊛ Annoted Parse Tree:

A parse tree constructing for a given input string in which each node showing the values of attributes is called an anoted parse tree. It is a parse tree showing the values of the attributes at each node. The process of computing the attribute values at the nodes is called annoting or decorating the parse tree.

Example 1: Lets take a grammar,

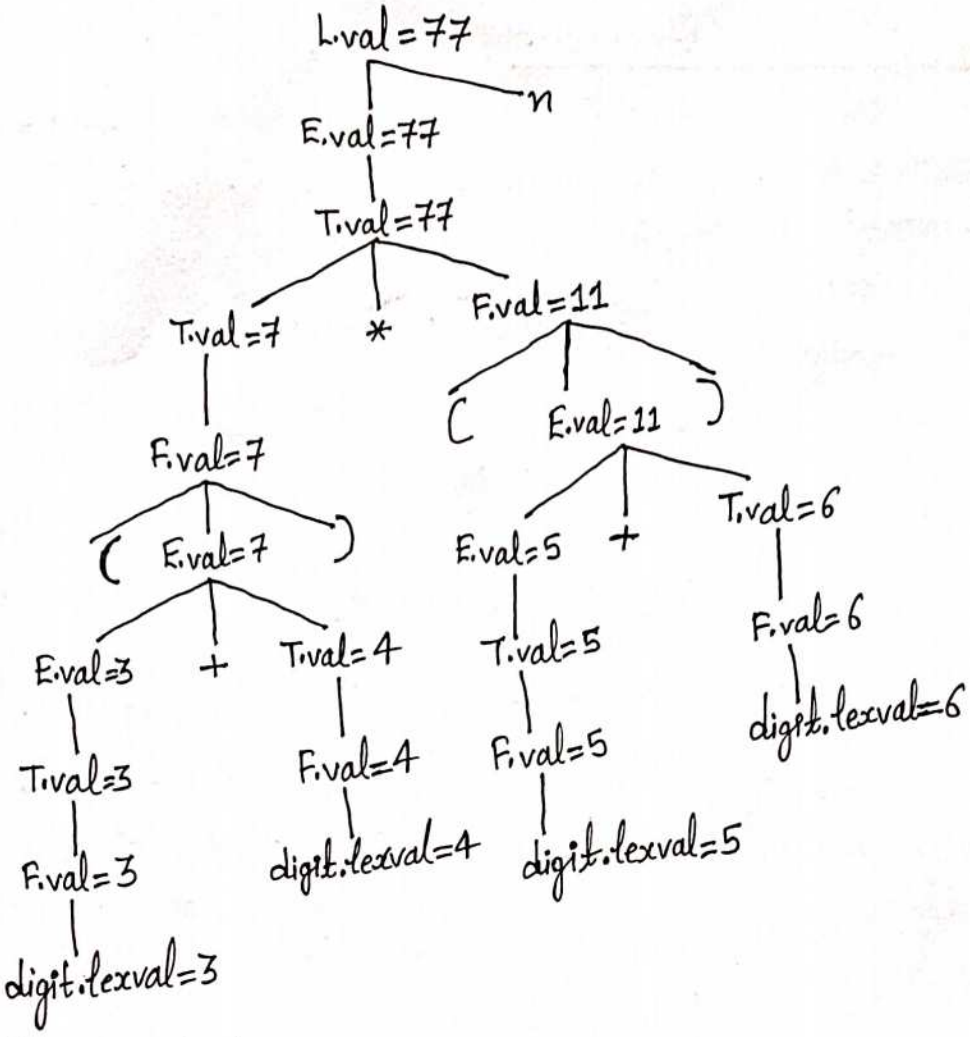
$L \to E\,n$
$E \to E1 + T$
$E \to T$
$T \to T_1 * F$
$T \to F$
$F \to (E)$
$F \to digit.$

Now the annoted parse tree for the input string 3*5+4 is,



Example 2: For the Syntax-Directed Definitions (SDD) of the grammar, $(3+4)*(5+6)n$, give annoted parse tree.

Solution:



⊛. S-Attributed Definitions:

If an SDT uses only synthesized attributes, it is called as S-attributed SDT. Attribute values for the non-terminal at the head is computed from the attribute values of the symbols at the body of the production. The attributes of an S-attributed SDD can be evaluated in bottom up order of nodes of the parse tree.

Example for S-attributed definitions:

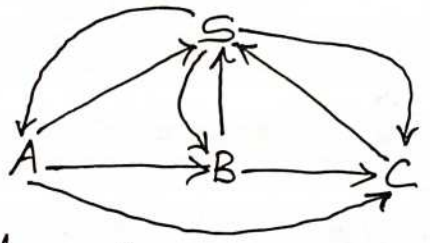
Production	Semantic Rules
L→E return	print (E.val)
E→E1+T	E.val= E1.val +T.val
E→T	E.val=T.val
T→F	T.val= F.val
F→digit	F.val=digit.lexval

Same example as before

⊛ L-Attributed Definitions:

This form of SDT uses both synthesized and inherited attributes with restriction of not taking values from right siblings. In L-attributed SDTs, a non-terminal can get values from its parent, child, and sibling nodes, as in the following production:

$S \rightarrow ABC$



S can take values from A, B, and C (synthesized). 'A' can take values from S only. B can take values from S and A. C can get values from S, A, and B. No non-terminal can get values from the sibling to its right like A does not take value from B or C. Attributes in L-attributed SDTs are evaluated by depth-first and left-to-right parsing manner.

Example:

Production	Semantic Rules
$T \rightarrow FT'$	T'.inh = F.val
$T' \rightarrow *FT_1'$	T_1'.inh = T'.inh * F.val

UNIT-3

1 question is asked for 5 marks from this unit

SYMBOL TABLE DESIGN AND RUNTIME STORAGE MANAGEMENT

⊛. Symbol Table Design: [Imp]

upto functions

Symbol Table is an important data structure created and maintained by the compiler in order to keep track of semantics of variable. It is built in lexical and syntax analysis phase. It is used by various phases of compiler as follows:

Lexical Analysis: Creates new table entries in the table, example like entries about token.

Syntax Analysis: Adds information regarding attribute type, scope, dimension, line of refrence, use etc. in the table.

Semantic Analysis: Uses available information in the table to check for semantics.

Intermediate Code generation: Helps in adding temporary variable information.

Code Optimization: Uses information present in symbol table for machine dependent optimization.

Target Code generation: Generates code by using address information of identifier present in the table.

Functions of a symbol table:

→To store the names of all entities in a structured form at one place.
→To verify if a variable has been declared or not.
→To determine the scope of a name (scope resolution).
→To access information associated with a given name.
→To add new information with a given name.
→To delete a name or group of names from the table.

⊛. Information Used by Compiler from Symbol Table:

Name:
→ Name of identifier.
→ May be stored directly or as a pointer to another character string in an associated string table names can be arbitrarily long.

Type:
→ Type of identifier: variable, label, procedure name etc.
→ For variable, it's type: basic types, derived types etc.

Location:
→ Offset within the program where the current definition is valid.

Other attributes: array limits, fields of records, ~~pattern~~ parameters, return values etc.

Scope:
→ Region of the program where the current definition is valid.

⊛ Basic Operations on a symbol table:

allocate → to allocate a new empty symbol table.
free → to remove all entries and free the storage for symbol table.
insert → to insert a name in a symbol table and return a pointer to it's entry.
lookup → to search for a name and return a pointer to it's entry.
set_attribute → to associate an attribute with a given entry.
get_attribute → to get an attribute associated with a given entry.

⊛. Storing Names in Symbol Table:

There are two types of name representation:

1. **Fixed Length Name:** A fixed space for each name is allocated in symbol table. In this type of storage if name is too small then there is wastage of space.

2. **Variable Length Name:** The amount of space required by string is used to store the names. The name can be stored with the name of starting index and length of each name.

⊛. Data Structures for Symbol Table:

Following are the commonly used data structures for implementing symbol table:

1). List Data Structure: In this method, an array is used to store names and associated information. A pointer "available" is maintained at end of all stored records and new names are added in the order as they arrive.

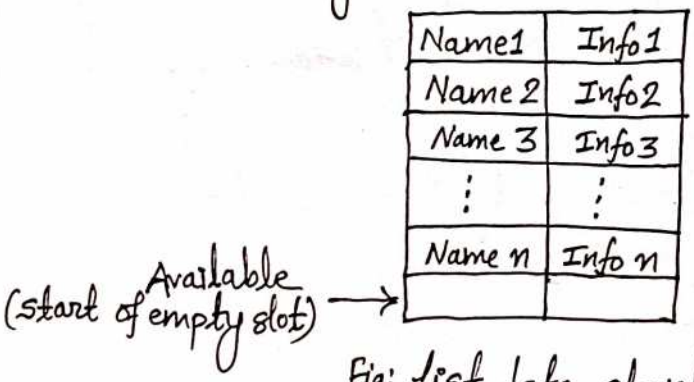


Fig: list data structure for symbol table.

2) Self Organizing List Data Structure: This implementation is using linked list. A link field is added to each record. A pointer "First" is maintained to point of first record of symbol table. Searching of names is done in order pointed by link of link field.

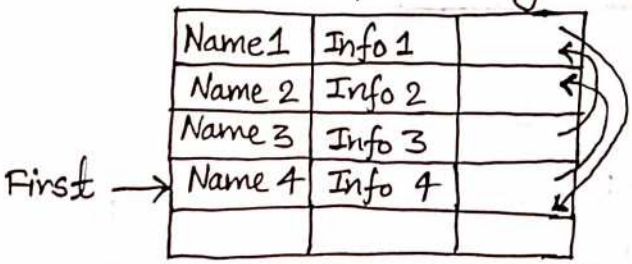


Fig: Self organizing list data structure for symbol table.

3) Binary Trees: When the organization of symbol table is by means of binary tree, the node structure will be as follows:

Left child	Symbol	Information	Right child

The left child field stores the address of previous symbol and right child field stores the address of next symbol. The symbol field is used to store the name of symbol, and information field is used to give information about symbol.

4) Hash Tables: In hashing scheme two tables are maintained: A Hash Table and Symbol Table. The hash table consist of k entries from 0,1, to k-1. These entries are basically pointers to symbol table pointing to the names of symbol table. To determine whether the 'Name' is in symbol table, we use a hash function 'h' such that h(name) will result any integer between 0 to k-1. We can search any name by

position = h(name)

Using this position we can obtain the exact location of name in symbol table.

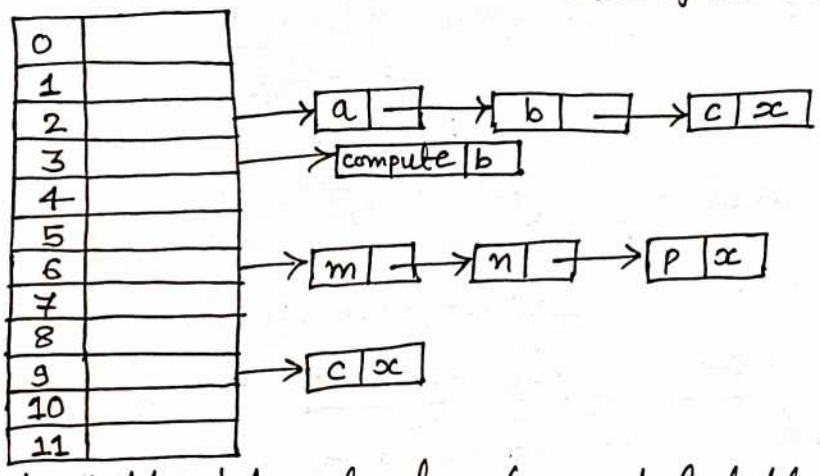


Fig: Hash table data structure for symbol table.

⊛. Run-time Storage Management:

Activation record: Activation record is a block of memory used for managing information needed by a single execution of a procedure. The following three-address statements are associated with the run-time allocation and de-allocation of activation records:

1. Call
2. Return
3. Halt
4. Action, a placeholder for other statements.

Activities performed by caller and callee during procedure call and return:

On caller's side:

→ Save registers for later use.
→ Arrange for the procedure arguments to be found by the procedure.
→ Call the procedure.
→ Copy the return value.
→ Throw away procedure arguments.
→ restore saved registers
→ continue

On the callee's side:

→ Control is transfered from the caller to the starting address.
→ Save registers for later use.
→ allocate storage for automatic local variables.
→ allocate storage for temporaries.
→ put return value in appropriate place.
→ Throw away local variables and temporaries.
→ restore saved registers
→ work

Different storage allocation strategies are:-

compile time

1) Static Storage Allocation: In static allocation, if memory is created at compile time, memory will be created in the static area and only once. It does not support dynamic data structure i.e, memory is created at compile time and de-allocated after program completion. The drawback with static storage allocation is recursion is not supported and size of data should be known at compile time. It's advantage is, it is faster ~~that~~ than stack storage allocation.

run-time

2) Stack Storage Allocation: Stack allocation is based on the idea of control stack.

↳ A stack is Last In First Out storage device where new storage is allocated and de-allocated at only one end, called the top of the stack.

↳ Storage is organized as a stack and activation records are pushed and popped as activations begin and end, respectively.

↳ Storage for the locals in each call of procedure is contained in the activation record for that call.

↳ The values of local are detected when the activation ends.

↳ At ~~run~~ run time, an activation record can be allocated and de-allocated by incrementing and decrementing top of the stack respectively.

Advantages:

→ It supports recursion as memory is always allocated on block entry.

→ It allows creating data structure dynamically.

Disadvantage:

→ Memory addressing can be done using pointers and index registers. Hence, this type of allocation is slower than static allocation.

run-time

3) Heap Storage Allocation: The de-allocation of activation records need not occur in a last-in first-out fashion, so storage cannot be organized as a stack. Heap allocation parcels out pieces of contiguous storage, as needed for activation records or other objects. Pieces may be de-allocated in any order. So over time the heap consist of alternate areas that are free and in use. Heap is an alternate for stack.

UNIT-4

There are three parts in this unit, this first part asks 10 marks in exam

4.1: INTERMEDIATE CODE GENERATOR

⊛ Intermediate Code Generation:

The front end translates the source program into intermediate representation from which the backend generates target code. Intermediate codes are machine independent codes, but they are close to machine instructions.

Advantages of using intermediate code representation:

→ If a compiler translates the source language to its target machine language without having the option for generating intermediate code, then for each new machine, a full native compiler is required.

→ Intermediate code eliminates the need of a new full compiler for every unique machine by keeping the analysis portion same for all the compilers.

→ The second part of compiler, synthesis, is changed according to the target machine.

→ It becomes easier to apply the source code modifications to improve code performance by applying code optimization techniques on the intermediate code.

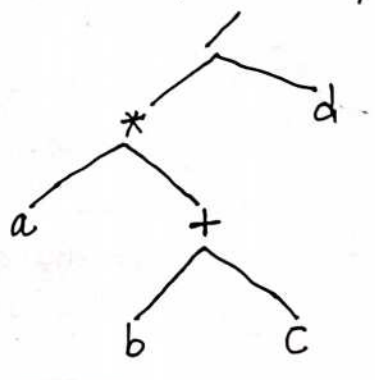
⊛. Intermediate Representations:

1). Graphical Representations:

[Imp]

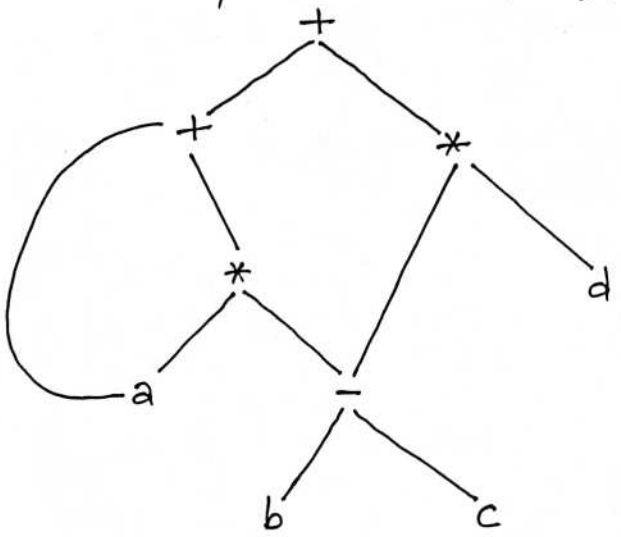
i) Syntax tree: Syntax tree is a graphical representation of given source program and it is also called variant of parse tree. A tree in which each leaf represents an operand and each interior node represents an operater is called syntax tree.

Example: Syntax tree for the expression a*(b+c)/d



1) Directed acyclic graph (DAG): A DAG for an expression identifies the [Imp] common sub expressions in the expression. It is similar to syntax tree, only difference is that a node in a DAG representing a common sub expression has more than one parent, but in syntax tree the common sub expression would be represented as a duplicate sub tree.

Example: DAG for the expression a+a*(b-c)+(b-c)*d.



2) Postfix notation: The representation of an expression in operators followed by operands is called postfix notation of that expression. In general if x and y be any two postfix expressions and OP is a binary operator then the result of applying OP to the x and y in postfix notation by "x y OP".

Examples:

1. (a+b)*c in postfix notation is: ab+c*
2. a*(b+c) in postfix notation is: abc+*

3) Three Address Code: The address code that uses at most three addresses, two for operands and one for result is called three address code. Each instruction in three address code can be described as a 4-tuple: (operator, operand1, operand2, result). A quadruple (Three address code) is of the form:

x=y op z where x, y and z are names, constants or compiler-generated temporaries and op is any operator.

We use the term "three-address code" because each statement usually contains three addresses (two for operands, one for the result).

Example1: Three address code for expression: (B+A)*(Y-(B+A))

Solution:

```
t1 = B+1
t2 = Y-t1
t3 = t1*t2
```

per line मा maximum 3 variable हुन्छ पर्छौ 1,2,3 गरि गए पनि हुन्छ

Maths मा जस्तो जसको precedence बढि हुन्छ त्यसलाई पहिला convert गर्छ here bracket first.

Example2: Three address code for expression:

```
i = 2*n + k
while i do
  i = i-k
```

Solution:

```
t1 = 2
t2 = t1*n
t3 = t2+k
i  = t3
L1: if i=0 goto L2
    t4 = i-k
    i  = t4
    goto L1
L2: .....
```

This first four lines for i = 2*n+k

We use two variables L1 and L2 when loop comes. L1 for true condition and L2 for false condition. Here instead of i=0 we can also write i=false

यहाँ पनि 3 variable हुन् L1, L2, र i

These three lines are for i=i-k which is body of loop

goes out of body i.e. L2 when i=0

⊛. Implementation of Three-Address Statements:

Three-address statements are implemented or represented by Quadruples and Triples.

Quadruples: A quadruple is a record structure with four fields, [Imp] which are op, arg1, arg2 and result. The op field contains an internal code for the operator. The three-address statement x = y op z is represented by placing y in arg1, z in arg2 and x in result.

	op	arg1	arg2	result
(0)	−	c		t1
(1)	*	b	t1	t2
(2)	−	c		t3
(3)	*	b	t3	t4
(4)	+	t2	t4	t5
(5)	=	t5		a

(0), (1), (2), ... numbering nothing else

first do three-address in rough as below then it is easy:

```
t1 = -c
t2 = b*t1
t3 = -c
t4 = b*t3
t5 = t2+t4
a  = t5
```

Fig: Quadruple representation of three-address statement a = b*-c+b*-c

Triples: A triple is a record structure with three fields, which are [Imp] op, arg1 and arg2. The result field of quadruples is absent here all other things are same, as quadruples. The fields arg1 and arg2, for the arguments of op, are either pointers to the symbol table or pointers into the triple structure.

	op	arg1	arg2
(0)	−	c	
(1)	*	b	(0)
(2)	−	c	
(3)	*	b	(2)
(4)	+	(1)	(3)
(5)	=	a	(4)

Rough: We use numbering here since result field having variable is absent there.

(0) −c
(1) b*(0)
(2) −c
(3) b*(2)
(4) (1)+(3)
(5) a=(4)

Fig: Triple representation of three-address statement a=b*−c+b*−c.

Example: Translate the expression x=(a+b)*(c+d)−(a+b+c)

a. Quadruples
b. Triples.

Solution: Three address code is:

```
t1 = a+b
t2 = c+d
t3 = t1 * t2
t4 = t1 + c
t5 = t3 - t4
x = t5
```

Quadruples:

	op	arg1	arg2	result
(0)	+	a	b	t1
(1)	+	c	d	t2
(2)	*	t1	t2	t3
(3)	+	t1	c	t4
(4)	−	t3	t4	t5
(5)	=	t5		x

Triple:

	op	arg1	arg2
(0)	+	a	b
(1)	+	c	d
(2)	*	(0)	(1)
(3)	+	(0)	c
(4)	−	(2)	(3)
(5)	=	x	(4)

Naming conventions for three address code:

S.code: three-address code for evaluating S.
S.begin: label to start of S.
S.after: label to end of S.
E.code: three-address code for evaluating E
E.place: a name that holds the value of E.

To represent three-address statement.

Gen (E.place '=' E1.place '+' E2.place)

↓ code generation

⇓

t3 = t1+t2

Syntax-Directed Translation into Three-Address Code

अहिले सबै हामिले expression लाई three-address code मा जाने, अब productions को 3-address code हेर्ने।

1) Assignment statements:

three address-code variable (ie, terminal को हुँदैन हामी further produce गर्न सकने non-terminal को मात्र निकाल्ने

newtemp() creates temprory storage for S

gen हामि expression को 3-address code निकाल्दा use गर्ने

Productions	Semantic rules
S → id = E	S.place = newtemp(); S.code = E.code || gen(id.place '=' E.place);
E → E1 + E2	E.place = newtemp(); E.code = E1.code || E2.code || gen(E.place '=' E1.place '+' E2.place)
E → E1 * E2	E.place = newtemp(); E.code = E1.code || E2.code || gen(E.place '=' E1.place '*' E2.place)
E → -E1	E.place = newtemp(); E.code = E1.code || gen(E.place '=' 'minus' E1.place)
E → (E1)	E.place = newtemp(); E.code = E1.code
E → id	E.place = id.name E.code = null

|| is concatenation operator here

right side three address निकाल्न मिल्ने non-terminal हुँदैन, so newtemp() गर्नु पर्दैन. id मा जे name आउछ त्यहि E को place मा जान्छ। code निकाल्नै so E.code is null.

2) Boolean Expressions: [Imp]

Production	Semantic Rules
$B \rightarrow B_1 \mid\mid B_2$	$B_1.true = B.true$ $B_1.false = newlabel()$ $B_2.true = B.true$ $B_2.false = B.false$ $B.code = B_1.code \mid\mid label(B_1.false) \mid\mid B_2.code$
$B \rightarrow B_1 \&\& B_2$	$B_1.true = newlabel()$ $B_1.false = B.false$ $B_2.true = B.true$ $B_2.false = B.false$ $B.code = B_1.code \mid\mid label(B_1.true) \mid\mid B_2.code$
$B \rightarrow !B_1$	$B_1.true = B.false$ $B_1.false = B.true$ $B.code = B_1.code$
$E \rightarrow id_1$ relop id_2	$E.code = gen('if'\ id_1.place\ relop\ id_2.place\ 'goto'\ E.true) \mid\mid gen('goto'\ E.false)$
$B \rightarrow true$	$B.code = gen(goto\ B.true)$
$B \rightarrow false$	$B.code = gen(goto\ B.false)$

logical OR मा कुनै एउटा मात्र true भए पनि true हुन्छ। दुवै false हुँदा मात्र false हुन्छ। So, सुरुमा B_1 true हुँदा B true भयो। But if B_1 false भए अब B true हुन B_2 मा depend गर्छ we do not know B_2 so we give it newlabel(). Now if B_2 is true B is true otherwise false finally we write 3 address code.

production मा || symbol आए logical OR हो। Semantic rule मा आए मात्र concatenation

$B_1.true = B.true$ हुँदा मा B true हुन्छ भनि decide गर्न सक्नेछैनौं, logical AND मा B true हुन B_1 र B_2 दुवै true हुनु पर्यो। So, B to be true now it depends on value of B_2 so newlabel() is given

logical AND. B true हुन दुवै B_1 र B_2 true हुनु पर्यो

relation operator (can be <, >, =, <=, >=, != etc.

3) Flow of control statements: [Imp]

Production	Semantic Rules
$S \rightarrow if(B)\ S_1$	$B.true = newlabel()$ $B.false = S.next$ $S_1.next = S.next$ $S.code = B.code \mid\mid label(B.true) \mid\mid S_1.code$
$S \rightarrow if(B)\ S_1\ else\ S_2$	$B.true = newlabel()$ $B.false = newlabel()$ $S_1.next = S.next$ $S_2.next = S.next$ $S.code = B.code \mid\mid label(B.true) \mid\mid S_1.code \mid\mid gen(goto\ S.next) \mid\mid label(B.false) \mid\mid S_2.code$

$S \rightarrow$ while $(B)\ S_1$

```
begin = newlabel()
B.true = newlabel()
B.false = S.next
S1.next = begin
S.code = label(begin) || B.code || label(B.true) ||
         S1.code || gen(goto begin).
```

Example : Generate three address code for the expression

```
if (x<5 || (x>10 && x==y)) x=3;
```

think of if condition in C program

This is similar to as;
if (x<5 || (x>10 && x==y))
{ x=3 } ; .....
i.e, if x<5 it goes to x=3
OR if x>10 and x==y then also it goes to x=3
otherwise goes out of if block .....

Logical OR

Solution:

```
L1: if x<5 goto L2
    else
        goto L3
L2: x=3 goto L5
L3: if x>10
      goto L4
    else
        goto L5
L4: if x==y
      goto L2
    else
        goto L5
L5: .....
```

4) Switch/case statements: [Imp]

Example: Convert the following switch statement into three address code:

```
Switch (i+j)
{
  Case1: x=y+z
  Case2: u=v+w
  Case3: p=q*w
  Default: s=u/v
}
```

Solution:

3 address code को use करके सीखेंगे अब आगे

```
t = i+j
L1: if t==1  goto L2
      else   goto L3
L2: x=y+z    goto L8
L3: if t==2  goto L4
      else   goto L5
L4: u=v+w    goto L8
L5: if t==3  goto L6
      else   goto L7
L6: p=q*w    goto L8
L7: s=u/v    goto L8
L8: ..........
```

5) Addressing array elements:

If the width of each array element is w, the the i^{th} element of array 'A' begins in location,

$$A[i] = base + (i - low) * w$$

where low is the lower bound on the subscript and base is the relative address of the storage allocated for the array. That is base is the relative address of A[low].

Example: Address of 15th element of array is calculated as below,
Suppose base address of array is 100 and type of array is integer of size 4 bytes and lower bound of an array is 10 then,

$$A[i] = base + (i - low) * w$$
$$\text{or, } A[15] = 100 + (15 - 10) * 4$$
$$= 100 + 20$$
$$= 120.$$

⇒ Similary for two dimensional array we have formula,

$$A[i_1, i_2] = base_A + ((i_1 - low_1) * n_2 + i_2 - low_2) * w$$

where low_1, low_2 are the lower bounds on values i_1 and i_2, n_2 is the number of values that i_2 can take.

Example: Let A be a 10×20 array, there are 4 bytes per word, assume $low_1 = low_2 = 1$. Find addressing array elements $A[i_1, i_2]$ and three-address code, for 2D array addressing.

Solution:

$$A[i_1, i_2] = base_A + ((i_1 - 1) * 20 + i_2 - 1) * 4$$
$$= base_A + (20i_1 - 20 + i_2 - 1) * 4$$
$$= base_A + (20i_1 - 21 + i_2) * 4$$
$$= base_A + 80i_1 - 84 + 4i_2$$

($base_A$, i_1 and i_2 not given so we write them as it is)

Now converting into three-address code as follows:

$t_1 = 80$
$t_2 = t_1 * i_1$
$t_3 = 4$
$t_4 = t_3 * i_2$
$t_5 = baseA + t_2$
$t_6 = t_5 - 84$
$t_7 = t_6 + t_4$
$A[i_1, i_2] = t_7$

⊛ Procedure Calls:

```
param x call p return y
```

Here, p is a function which takes x as a parameter and returns y.

Procedure calls have the form:

```
param x1
param x2
. . . . . .
param xn
call p, n
```

corresponding to the procedure call $p(x1, x2, \ldots, xn)$.

return statement:

They have the form return y, representing a returned value is optional.

⊛ **Back patching:** The easiest way to implement the syntax-directed definitions for boolean expressions is to use two passes. While generating code for boolean expressions and flow-of-control statements during one single pass we may not know the labels that control must go at the time the jump statements are generated. Hence a series of branching statements with the targets of the jumps left unspecified is generated. Each statement will be put on a list of goto statements whose labels will be filled in when the proper label can be determined. We call this subsequent filling in of labels backpatching.

4.2 Code Generator

asks for 5 marks in exam normally.

⊛Factors Affecting code generator/code generator design issues: [Imp]

The code generator mainly concern with:

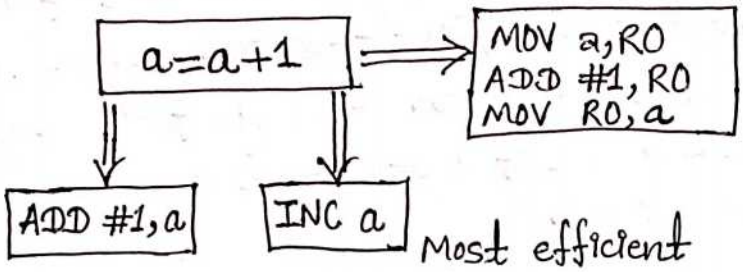
1) Input to the code generator: The input to the code generator is intermediate representation together with the information in the symbol table.

2) The Target Program: The output of the code generator is target code. Typically, the target code comes in three forms such as: absolute machine language, relocatable machine language and assembly language.

The advantage of producing target code in absolute machine form is that it can be placed directly at the fixed memory location and then can be executed immediately. The benefit of such target code is that small programs can be quickly compiled.

3) The target machine: Implementing code generation requires understanding of the target machine architecture and its instruction set.

4) Instruction Selection: Instruction selection is important to obtain efficient code. Suppose we translate three-address code,



5) Register Allocation: Since registers are the fastest memory in the computer, the ideal solution is to store all values in registers. We must choose which values are in the registers at any given time. Actually this problem has two parts:

i) Which values should be stored in registers?

ii) Which register should each select to store value?

The reason for the second problem is that often there are register requirements, e.g, floating-point values in floating-point registers and certain requirements for even-odd register pairs for multiplication/division.

6) Evaluation order: The order of the target code can be affected by the order in which the computations are performed.

⊛ Basic blocks:

A basic block is a sequence of consecutive instructions in which flow of control enters by one entry point and exit to another point without halt or branching except at the end.

Example:

```
    MOV 1, R0
    ADD n, R0
    MOV 2, R1
    MUL R0, R1
    JMP L2
L1: MUL 2, R0
    SUB 1, R1
L2: MUL 3, R1
    JMPNZ R1, L1
```

⟹

```
MOV 1, R0
ADD n, R0
MOV 2, R1
MUL R0, R1
JMP L2
```

```
L1: MUL 2, R0
    SUB 1, R1
```

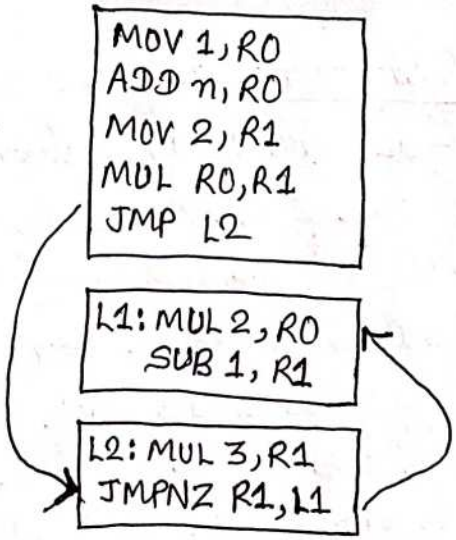
```
L2: MUL 3, R1
    JMPNZ R1, L1
```

⊛ Flow Graphs: A flow graph is a graphical representation of a sequence of instructions with control flow edges. A flow graph can be defined at the intermediate code level or target code level. The nodes of flow graphs are the basic blocks ~~of given sequence of instructions then such group of blocks~~ and flow-of-control to immediately follow node connected by directed arrow. Simply, if flow of control occurs in basic blocks of given sequence of instructions then such group of blocks is known as flow graphs.

Example:

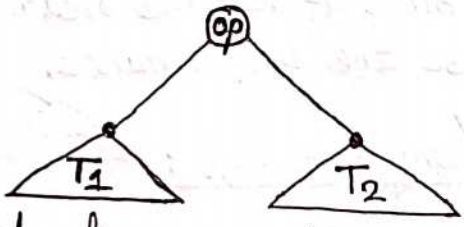
```
    MOV 1, R0
    ADD n, R0
    MOV 2, R1
    MUL R0, R1
    JMP L2
L1: MUL 2, R0
    SUB 1, R1
L2: MUL 3, R1
    JMPNZ R1, L1
```

⟹



⊛ Dynamic programming code-generation algorithm:

The dynamic programming algorithm can be used to generate code for any machine with r interchangable registers $R_0, R_1, \ldots, R_{r-1}$ and load, store, and add instructions. For simplicity, we assume every instruction costs one unit, although the dynamic programming algorithm can easily be modified to work even if each instruction has its own cost.



Contiguous evaluation: Compute the evaluation of T_1, T_2, then evaluate root.
Non-contiguous evaluation: First evaluate part of T_1 leaving the value in a register, next evaluate T_2, then return to evaluate the rest of T_1.

The dynamic programming algorithm uses contiguous evaluation and proceeds in three phases:

1). Compute bottom-up for each node n of the expression tree T, an array C of costs, in which the ith component C[i] is the optimal cost of computing the subtree S rooted at n into a register assuming i registers are available for the computation, for $1 <= i <= r$.

2). Traverse T, using the cost vectors to determine which subtrees of T must be computed in memory.

3). Traverse each tree using the cost vectors and associated instructions to generate the final target code. The code for the subtrees computed into memory locations is generated first.

4.3 Code Optimization

The code optimization in the synthesis phase is a program transformation technique, which tries to improve the intermediate code by making it consume fewer resources (i.e, CPU, Memory) so that faster-running machine code will result.

Optimization of the code is often performed at the end of the development stage since it reduces readability and adds code that is used to increase the performance.

Code optimization defn and need or importance is Imp!

⊛ Need of code optimization / why optimize? :

Code optimization is needed because optimization helps to:

→ Reduce the space consumed and increases the speed of compilation.

→ Manually analyzing datasets involves a lot of time. Hence we make use of software like Tableau for data analysis. Similarly manually performing the optimization is also tedious and is better done using a code optimizer.

→ An optimized code often promotes re-usability.

⊛ Criteria of code optimization:

→ The optimization must be correct, it must not, in any way, change the meaning of program.

→ Optimization should increase the speed and performance of the program.

→ The compilation time must be kept reasonable.

→ The optimization process should not delay the overall compiling process.

⊛ Basic optimization techniques: [Imp]

Optimizations techniques are classified into two categories:
- → Machine Independent optimization techniques
- → Machine dependent optimization techniques.

1) Machine Independent optimization techniques:

Machine independent optimization techniques are program transformations that improve the target code without taking into consideration any properties of the target machine.

a) Constant Folding: As its name suggests, it involves folding the constants. The expressions that contain the operands having constant values at compile time are evaluated. Those expressions are then replaced with their respective results.

Example: Circumference of Circle = (22/7) × Diameter

Here,
- → This technique evaluates the expression 22/7 at compile time.
- → The expression is then replaced with its result 3.14.
- → This saves time at run time.

b) Constant Propagation: In this technique, if some variable has been assigned some constant value, then it replaces that variable with its constant value in the further program during compilation. The condition is that the value of variable must not get alter in between.

Example: Pi = 3.14, Radius = 10, Area of circle = Pi × Radius × Radius.

Here,
- → This technique substitutes the variables 'pi' and 'radius' at compile time.
- → It then evaluates the expression 3.14×10×10
- → The expression is then replaced with its ~~resu~~ result 314.
- → This saves the time at run time.

c) Redundant Code Elimination: In computer programming, redundant code is source code or compiled code in a computer program that is unnecessary such as: code that is never executed (unreachable code).

Example: x = y+z
a = 2+y+b+z

That is reduced by,
a = 2+x+b.

d) **Variable Propagation:** Variable propagation means use of one variable instead of another.

Example: $x = r$
$A = pi * x^2$
That is reduced by, $A = pi * r^2$

e) **Strength reduction:** It involves reducing the strength of expressions. This technique replaces the expensive and costly operators with the simple and cheaper ones.

Example:

Code before optimization	Code after optimization
B = A × 2	B = A + A

→ This is because the cost of multiplication operator is higher than that of addition operator.

f) **Loop Optimization:** ⟷ Defn: Loop optimization is the process of increasing execution speed and reducing the overheads associated with loops. Following are loop optimization techniques.

i) **Code Motion / Frequency Reduction:** It is a technique which moves the code outside the loop.

Example:
```
while (i<5000)
    x = i*sin(A)*cos(A);
```

This can be optimized as;
```
t = sin(A)*cos(A);
while (i<5000)
    x = i*t;
```

ii) **Loop jamming / Loop Fusion:** In loop fusion method several loops are merged to one loop.

Example:
```
for i=1 to n do
    for j=1 to m do
        a[i,j]=10.
```

It can be written as;
```
for i=1 to n*m do
    a[i]=10
```

iii) **Loop Unrolling:** The number of jumps and tests can be reduced by writing code two times.

Example:
```
int i=1;
while (i<=100)
{ a[i]=b[i];
  i++;
}
```

It can be written as;
```
int i=1;
while (i<=100)
{ a[i]=b[i];
  i++;
  a[i]=b[i];
  i++;
}
```

2) Machine Dependent Optimization Techniques:

Machine dependent optimization techniques are based on register allocation and utilization of special machine-instruction sequences. It is done after the target code has been generated and when the code is transformed according to the target machine architecture.

Peephole Optimization: Peephole optimization is a simple and effective technique for locally improving target code. This technique is applied to improve performance of the target program by examining the short sequence of target instructions. (called the peephole) and replace these instructions replacing by shorter or faster sequence whenever possible. Peephole is a small, moving window on the target program. Peephole optimization techniques are as follows:

a) Redundant Load and Store Elimination: In this technique the redundancy is eliminated.

Example:

Initial code:
```
y=x+5;
i=y;
z=i;
w=z*3;
```

Optimized code
```
y=x+5;
i=y;
w=y*3;
```

b) The Flow of Control Optimization:

i) Dead Code Elimination: It involves eliminating the dead code i.e, statements of code which never executes or are unreachable.

Example:

Code before optimization
```
i=0;
if(i==1)
{
  a=x+5;
}
```

Code after optimization
```
i=0;
```

ii) Avoid jump on jump: The unnecessary jumps can eliminate in either the intermediate code or the target code.

We can replace the jump sequence:
```
Goto L1
.....
L1: goto L2
```
By the sequence:
```
Goto L2
.....
L1: goto L2
```

c) Algebraic Simplification: Peephole optimization is an effective technique for algebraic simplification. The statements such as $x = x+0$ or $x = x*1$ can be eliminated by peephole optimization.

d) Machine Idioms: The target instructions have equivalent machine instructions for performing some operations. Hence we can replace these target instructions by equivalent machine instructions in order to improve the efficiency.

Example: Some machines have auto-increment or auto-decrement addressing modes.

e) Strength reduction: It involves reducing the strength of expressions. This technique replaces the expensive and costly operators with the simple and cheaper ones.

Example: Code before optimization:

$B = A \times 2$

Code after optimization:

$B = A + A$

Compiler Design and Construction (Marking Scheme) With Imp Topics:

Unit1: (3 hrs) : 5 marks (Analysis phase, Synthesis phase, compiler vs interpreter, one pass vs. Multipass compiler)

Unit2: (22 hrs):

2.1 Lexical Analysis: 10 marks (lexemes, patterns, tokens, thomsons construction, subset construction)

2.2 Syntax Analysis: 20 marks (role of syntax analyzer, Left recursion, left factoring, LL(1) parsing table, handle, LR(0) item, cannonical LR(0) collection, SLR parsing tables, cannonical LR(1) collection, LR(1), LALR(1), Top-down vs bottom-up parsing)

2.3 Semantic Analysis: 10 marks (Type checking of expressions, Static vs. dynamic type checking, STD, STDS)

Unit3: (4 hrs):

Symbol Table Design: 5 marks

Run-time storage management: 5 marks

(very short unit everything imp read all)

Unit4: (16 hrs):

4.1 Immediate Code Generator: 10 marks (Role of immediate code generator, Syntax tree, DAG, Postfix notation, finding 3 address code of expressions and statements)

4.2 Code Generator: 5 marks (code generator design issues)

4.3 Code Optimization: 5 marks (defn of code optimization with its need, basic optimization techniques)

If my notes really helped you,then you can support me on esewa for my hardwork.

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