COMPILER DESIGN

- www.ankurgupta.net

* These notes have been prepared from the following book :-

Principles of Compiler Design
by Aho, Ullman

Kindly refer the above book for more details.

Compiler Design

High Level Language → Compiler → Low-level Language

Major parts of a compiler :-

Two major parts :-

(1) **Analysis Phase :-**

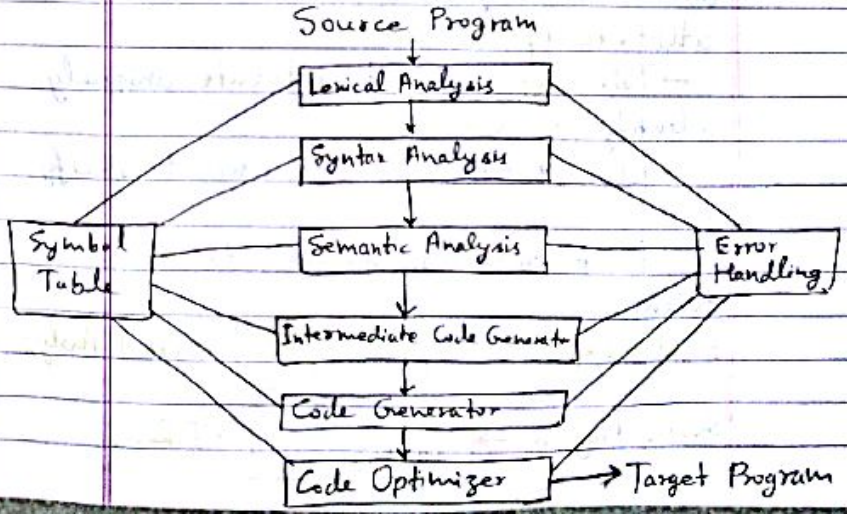
An intermediate representation is created from the given source program.

(i) Lexical Analyzer,
(ii) Syntax Analyzer,
(iii) Semantic Analyzer are phases in it.

(2) **Synthesis Phase :-**

Equivalent target program is created from this intermediate representation.

(i) Intermediate Code Generator,
(ii) Code Generator
(iii) Code Optimizer are phases in it.



Phases vrs Passes :-

Passes refer to the number of times the compiler has to traverse through the entire program. Several phases are grouped into one pass.

Cross Compiler :-

A compiler that runs on one machine (A) and produces a code for another machine (B).

Lexical Analysis :-

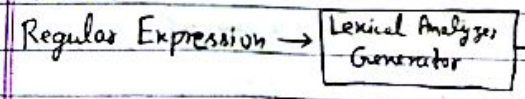
→ Lexical Analyzer reads a source program character by character to produce tokens.

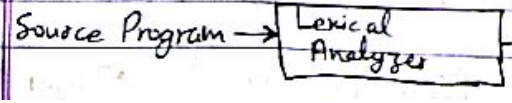
→ A token can represent more than one lexeme, additional information should be held for that specific lexeme. This additional information is called as the attribute of the token.

→ Token type and its attribute uniquely identify a lexeme.

→ Regular expressions are used to specify patterns.

→ Finite Automata is used to recognise tokens





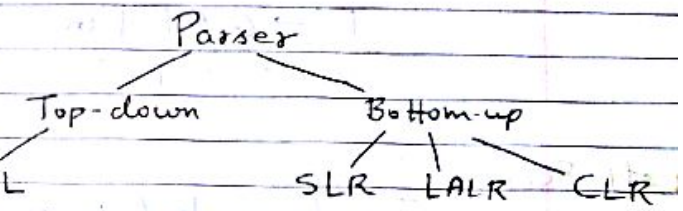
Syntax Analysis

→ Syntax Analyzer is also known as parser.

→ The syntax of a programming language is described by a CFG.

→ A CFG gives a precise syntactic specification of a programming language.

→ Parser works on a stream of tokens.



→ Top-down parsers try to find the left-most derivation of the given source program.

→ Bottom-up parsers try to find the right-most derivation of the given source program in reverse order.

→ Both top down and bottom-up parsers scan the input from left-to-right.

→ Bottom-up parsers are called as Shift-Reduce Parsers.

Ambiguity :-

→ An unambiguous grammer should be written to eliminate the ambiguity.

Example :- Disambiguate the grammer :-

$E \to E+E \mid E*E \mid E \wedge E \mid id \mid (E)$

$\wedge$ (Right to left)

*, + (Left to right).

Solution :-

$E \to E+T \mid T$

$T \to T*F \mid F$

$F \to G \wedge F \mid G$

$G \to id \mid (E)$

Left Recursion :-

Top-down techniques can not handle left-recursive grammers.

Left Factoring :-

A predictive parser (a topdown parser without backtracking) insists that the grammer must be left-factored.

Example :- $A \to abB \mid aB \mid cdg \mid cdeB \mid cdfB$

$\Downarrow$

$A \to aA' \mid cdg \mid cdeB \mid cdfB$

$A' \to bB \mid B$

$\Downarrow$

$A \to aA' \mid cdA'', \quad A' \to bB \mid B,$

$A'' \to g \mid eB \mid fB$

YACC :-

YACC generates C-code for a syntax analyzer, or parser.

Tokens from LEX → [YACC] → Syntax-tree

Top-Down Parsing :-

(1) Recursive-Descent Parsing :-

- → Backtracking is needed, Not efficient.
- → General purpose, not widely used.

(2) Predictive-Parsing :-

- → No backtracking, efficient
- → Uses LL(1) grammers.

Predictive Parser :-

→ It can uniquely choose a production rule by just looking the current symbol.

→ Non-Recursive (Table Driven) Predictive parser is also known as LL(1) parser.

→ We eliminate the left recursion in the grammer, and left-factor it. But it may not be suitable for predictive parsing (not LL(1) grammer).

Two types :-

(1) Recursive Predictive Parsing

(2) Non-Recursive Predictive Parsing LL(1)

Recursive Predictive Parsing :-

Each non-terminal corresponds to a procedure.

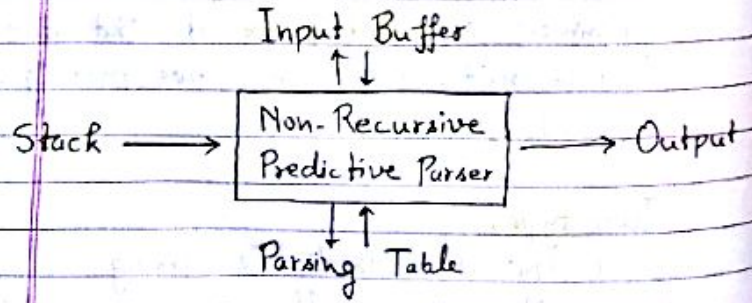
Example :- $A \rightarrow aBb \mid bAB$

```
proc A {
    case of the current token {
        'a' :- match the current token with a,
               and move to next token.
               - call B
               - match the current token with
                 b, and move to the next token.
        'b' - match the current token with
              b and move to the next token
              - call 'A'
              - call 'B'
```

Non-Recursive Predictive Parsing :-

→ Table-driven parser

→ Also known as LL(1) parser.



Example :- $S \rightarrow aBa$, $B \rightarrow bB \mid \wedge$,

	a	b	$	
S	$S \rightarrow aBa$			← LL(1) Parsing Table
B	$B \rightarrow \wedge$	$B \rightarrow bB$		

Solution :-

Stack	Input	Output
$ S	abba $	$S \rightarrow aBa$
$ aBa	abba $	
$ aB	bba $	$B \rightarrow bB$
$ aBb	bba $	
$ aB	ba $	$B \rightarrow bB$
$ aBb	ba $	
$ aB	a $	$B \rightarrow \wedge$
$ a	a $	
$	$	Accept.

Constructing LL(1) Parsing Tables :-

→ Two functions are used :-
FIRST & FOLLOW

→ FIRST(α) is a set of the terminal symbols which occur as first symbols in strings derived from α.

→ FOLLOW(A) is the set of terminals which occur immediately after the non-terminal A in the strings derived from the starting symbol.

Computing FIRST for any string X :-

→ If X is a terminal symbol :-
FIRST(X) = {X}

→ If X is a non-terminal symbol, and X → ∧ is a production rule, then ∧ is in FIRST(X).

→ If X is a non-terminal symbol, and X → $Y_1 Y_2 \dots Y_n$ is a production rule, then :-
(i) If a terminal symbol a in FIRST(Y_i) and ∧ is in all FIRST(Y_j) for $j = 1, 2, \dots i-1$, then a is in FIRST(X).
(ii) If ∧ is in all FIRST(Y_i) for $i = 1, \dots n$, the ∧ is in FIRST(X).

Computing FOLLOW (for non-terminals) :-

→ If S is the start symbol, then :-
$ is in FOLLOW(S).

→ If A → αBβ is a production rule, then everything in FIRST(β) is FOLLOW(B) except ∧

→ If (A → αB) or (A → αBβ and ∧ is in FIRST(β)), then :-
everything in FOLLOW(A) is in FOLLOW(B).

Algorithm for constructing LL(1) Parsing Table :-

For each production rule A → α of a grammer G :-

→ For each terminal a in FIRST(α), add A → α to M[A, a]

→ If ∧ is in FIRST(α), then :-
for each terminal a in FOLLOW(A) add A → α to M[A, a]

→ If ∧ is in FIRST(α) and $ in FOLLOW(A), then :-
add A → α to M[A, $].

All other undefined entries of the parsing table are error entries.

LL(1) Grammers :-

LL(1) → One input symbol used as a look-ahead symbol to determine parser action.
- L: Input scanned from left to right
- L: Left-most derivation

→ A grammer whose parsing table has no multiple entries is said to be LL(1) grammer.

→ A left-recursive grammer can not be a LL(1) grammer.

→ A grammer is not left factored, it cannot be a LL(1) grammer.

→ An ambiguous grammer can not be a LL(1) grammer.

Example:- $E \to TE'$, $E' \to +TE' | \wedge$,
$T \to FT'$, $T' \to *FT' | \wedge$,
$F \to (E) | id$

Construct LL(1) parsing table:-

Solution:-

FIRST(F) = {(, id},
FIRST(T') = {*, ∧}, FIRST(T) = {(, id}
FIRST(E') = {+, ∧}, FIRST(E) = {(, id}
FIRST(TE') = {(, id}, FIRST(+TE') = {+},
FIRST(∧) = {∧}, FIRST(FT') = {(, id},
FIRST(*FT') = {*}, FIRST((E)) = {(},
FIRST(id) = {id}

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

	id	+	*	(	)	$
E	$E \to TE'$			$E \to TE'$		
E'		$E' \to +TE'$			$E' \to \wedge$	$E' \to \wedge$
T	$T \to FT'$			$T \to FT'$		
T'		$T' \to \wedge$	$T' \to *FT'$		$T' \to \wedge$	$T' \to \wedge$
F	$F \to id$			$F \to (E)$		

Bottom-Up Parsing:-

It is also known as shift-reduce parsing.

Handle:-

If the grammer is unambiguous, then every right-sentential form of the grammer has exactly one handle.

A right-most derivation in reverse can be obtained by handle-pruning.

Conflicts during Shift Reduce Parsing:-

(1) Shift/Reduce Conflict:-
Whether make a shift operation or a reduction.

(2) Reduce/Reduce Conflict:-
Passes cannot decide which of several reductions to make.

→ If a shift-reduce parser can not be used for a grammer, that grammer is called as Non-LR(k) grammer.

LR(k) Grammer :-

LR(k) → k-input symbols used as a lookahead symbol to determine parser action.

- Input scanned from left to right.
- Right most derivation

→ An ambiguous grammer can never be a LR grammer.

Types of Shift-Reduce Parsing :-

Two main categories :-

(1) Operator - Precedence Parser

(2) LR-Parsers :-

Covers wide range of grammers :-

(i) SLR - Simple LR

(ii) CLR - Most general LR (Canonical LR)

(iii) LALR - Intermediate LR (Look ahead)

SLR, CLR, LALR work same, only their parsing tables are different.

Operator Precedence Parsing :-

Operator Grammar :-

→ Small, but an important class of grammars.

In an operator grammar, no production rule can have :-

(i) ∧ at right side,

(ii) two adjacent ⊙ non-terminals at the right side.

Using precedence relations to find handles :-

(1) Scan the string from left end until the first '·>' is encountered.

(2) Then scan backwards (to the left) over any '=·' until a '<·' is encountered.

(3) The handle contains everything to left of the first '·>' and to the right of the '<·' is encountered.

	id	+	*	$
id		·>	·>	·>
+	<·	·>	<·	·>
*	<·	·>	·>	·>
$	<·	<·	<·	

Example :- $E \to E+E$, $E \to E*E$, $E \to id$

Stack	Input	Action
$	id + id * id $	shift
$ id	+ id * id $	Reduce
$ E	+ id * id $	Shift
$ E +	id * id $	Shift
$ E + id	* id $	Reduce
$ E + E	* id $	Shift
$ E + E *	id $	Shift
$ E + E * id	$	Reduce
$ E + E * E	$	Reduce
$ E + E	$	Reduce
$ E	$	Accept.

Advantages :-

Powerful enough for expressions in programming languages.

Disadvantages :-

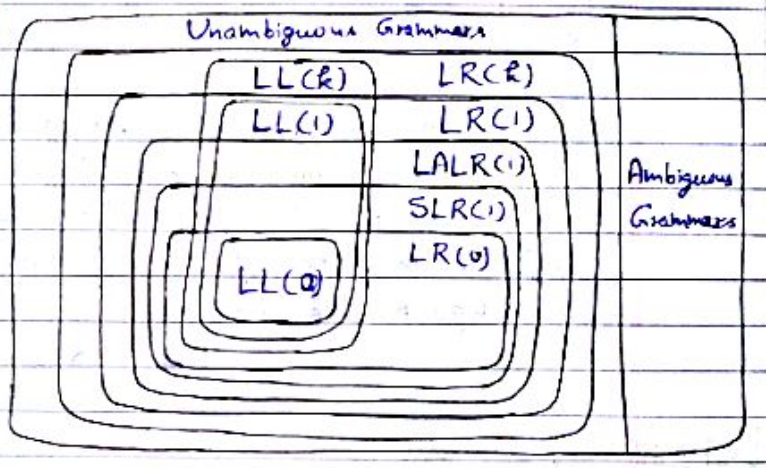
(1) It can not handle the unary minus (the lexical analyzer should handle that).

(2) Difficult to decide which language is recognized by the grammar.

LR-Parsing :-

→ LR parsing is a non-backtracking shift reduce parsing.

→ An LR-parser can detect a syntactic error as soon as it is possible to do so in a left-to-right scan of the input.



$LL(k) \subset LR(k)$

$LR(0) \subset SLR(1) \subset LALR(1) \subset LR(1)/CLR \subset LR(k)$

Canonical LR is also referred to as LR(1).

→ LALR parsers are often used in practice because LALR parsing tables are smaller than Canonical LR parsing tables.

→ The number of states in SLR and LALR parsing tables for a grammar G are equal.

→ We can create LR-parsing tables for ambiguous grammars, but they will have conflicts. We can resolve these conflicts in favor of one of them to disambiguate the grammar.

Definition of Handle :-

A handle of a right sentential form γ is a production rule $A \to \beta$ and a position of γ where the string β may be found and replaced by A.

If the grammar is unambiguous, then every right sentential form of the grammar has exactly one handle.

Intermediate Code Generation

Intermediate Codes are machine independent codes, but they are close to machine instructions.

Syntax trees, Postfix Notation, three-address codes can be used as intermediate language.

Three Address Code :-

$$A = -B * (C + D)$$

Three address code is as follows :-

$$T_1 = -B$$
$$T_2 = C + D$$
$$T_3 = T_1 + T_2$$
$$A = T_3$$

Quadruple :-

	Operator	Operand 1	Operand 2	Result
(1)	-	B		T_1
(2)	+	C	D	T_2
(3)	*	T_1	T_2	T_3
(4)	=	T_3		A

Triple :-

	Operator	Operand 1	Operand 2
(1)	-	B	
(2)	+	C	D
(3)	*	(1)	(2)
(4)	=	A	(3)

Indirect Triple:-

	Statement
(0)	(56)
(1)	(57)
(2)	(58)
(3)	(59)

	Operator	Operand1	Operand2
(56)	-	B	
(57)	+	C	D
(58)	*	(56)	(57)
(59)	=	A	(58)

Code Optimization

(1) Common Sub-expression Elimination:-

```
a = (b * c)                T1 = b * c
|                    ⇒      a = T1
|                           |
d = (b * c) + x - y        d = T1 + x - y
```

(2) Compile Time Evaluation:-

(i) A = 2 * (22.0/7.0) * r

Perform 2 * (22.0/7.0) at compile time.

(ii)
```
x = 12.4                   Evaluate x/2.3 as
|                    ⇒     12.4/2.3 at compile
|                          time.
y = x/2.3
```

~~(Dead Code Elimination)~~

(3) Variable Propagation:-

```
c = a * b                  c = a * b
x = a                      x = a
|                    ⇒     |
|                          |
d = (x) * b + 4            a = a * b + 4
```

Here, after variable propagation, a*b and x*b will be identified as common subexpressions.

(4) Dead Code Elimination :-

Variable propagation often leads to making assignment statement into dead code.

```
c = a*b                    c = a*b
x = a                      |
|                  ⇒       |
|                          |
d = a*b+4                  d = a*b+4
```

(5) Code Motion :-

→ Reduce the evaluation frequency of expressions.

→ Bring loop-invariant statements out of the loop.

```
a = 200;                   a = 200;
while (a>0)                b = x+y;
{                          while (a>0)
  b = x+y;          ⇒      {
  if (a*b==0)                if (a*b==0)
      printf("%d", a);           printf("%d", a);
}                          }
```

(6) Induction Variables and Strength Reduction :-

→ An induction variable is used in loop for the following kind of assignment :-

$i = i + \text{constant}$

→ Strength reduction means replacing the high strength operator by low strength.

```
i = 1;                     i = 1;
while (i<10)               t = 4;
{                          while (t<40)
  |                        {
  |                  ⇒     |
  y = i*4;                 y = t;
  |                        t = t+4;
  |                        |
}                          }
```

PPL

Typed versus Untyped Languages :-

A language is typed if the specification of every operation defines types of data to which the operation is applicable.

In contrast, an untyped language, such as most assembly languages, allows any operation to be performed on any data, which are generally considered to be sequences of bits of various lengths.

Weak and Strong Typing :-

Weak typing allows a value of one type to be treated as another.

Strong typing prevents the above.

Strongly typed languages are often termed as type-safe.

Static versus Dynamic Typing :-

A programming language is said to be statically typed when type checking is performed during compile type.

A programming language is said to be dynamically typed when majority of its type checking is performed at run-time.

In dynamically typed languages, values have types, but variables do not, that is a variable can refer to a value of any type.

Activation Records :-

Information needed by a single execution of a procedure is managed using a contiguous block of storage called activation record.

An activation record is allocated when a procedure is entered, and it is de-allocated when that procedure exited.

Storage Management :-

(1) Static Storage Management :

Static allocation is done during compilation that remains fixed throughout execution.

It requires no run-time storage management software.

Global data in C is allocated using static storage.

It is very efficient, but it is ~~incomplete~~ incompatible with recursive subprogram calls.

(2) Dynamic Storage Management :-

It is also termed as heap storage management.

The need of heap storage arises when a language permits storage to be allocated and freed at arbitrary points during program execution.

(3) Stack based Storage Management :-

It is used when storage requirements are not known at compile time, but the requests obey a Last In First Out order.

Examples :-

(i) Local variables in a procedure in C.

(ii) Procedure call information (return address etc).

→

→ Stack-based is allocation is used in recursive sub-programs.