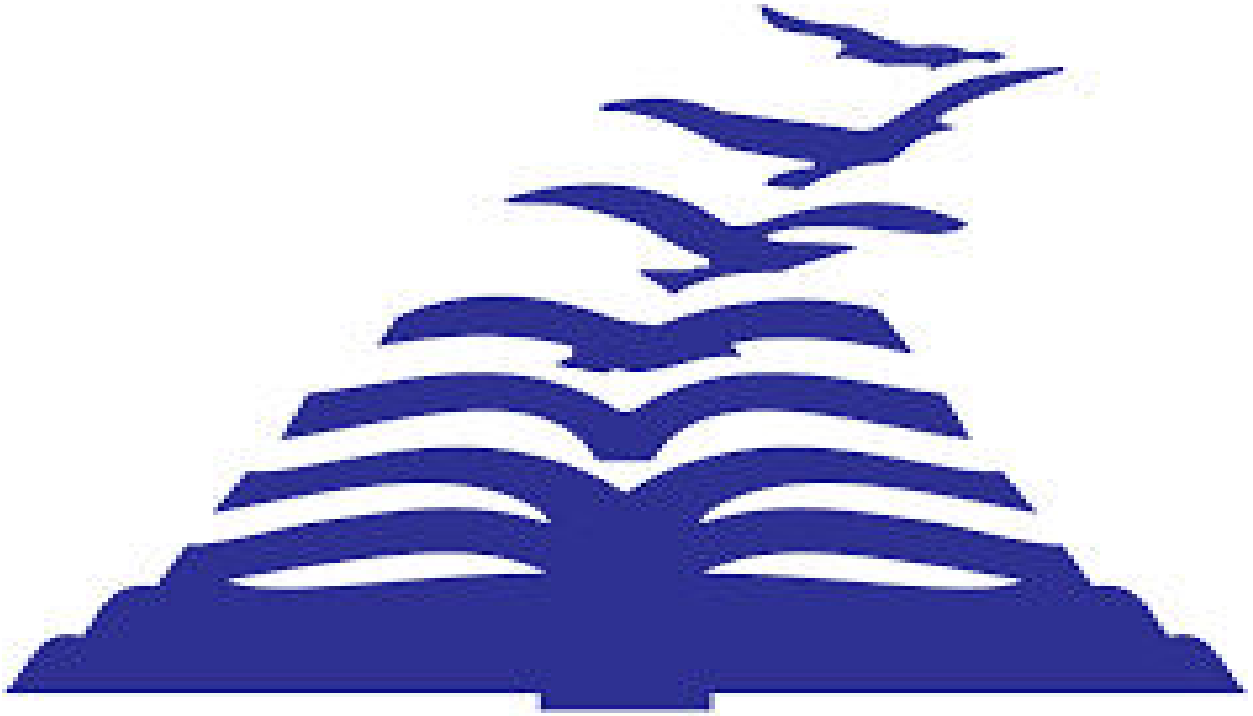

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CSE 217 – Compiler Design

Introduction

Instructors

Instructor-in-charge : **Dr. Islabudeen. M**

Instructors : **Mr. Sukruth Gowda M.A,**

Mr. Prasad P.S,

Mr. Rahul Biswas,

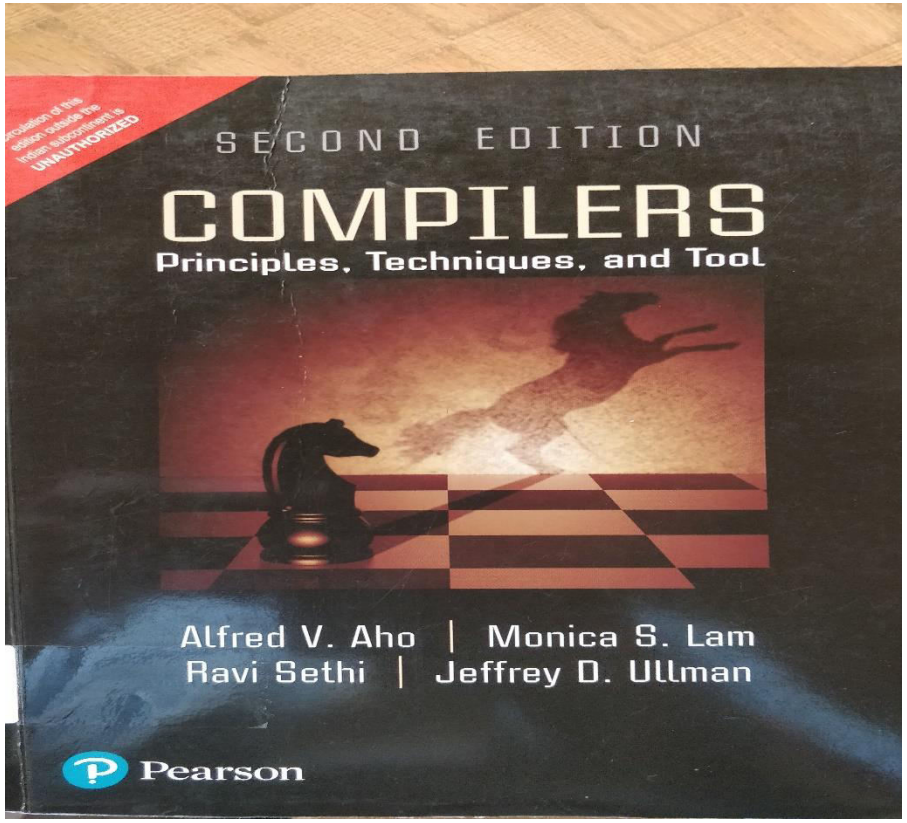
Ms. Shivali Shukya

Mr. Shine V.J

Evaluation Components

	Duration (minutes)	% Weightage	Marks	Date & Time
Test 1	60 min	20	40	To be announced by COE
Test 2	60 min	20	40	To be announced by COE
Quiz / Class Test	60 min	20	40	To be announced by Later
Comprehensive exam	180 min	40	100	To be announced by COE

Slides are Mostly From



Text Books:

1. Alfred V. Aho, Jeffrey D Ullman, “Compilers: Principles, Techniques and Tools”, Pearson second Edition, 2013.

Reference Books:

1. Jean Paul Tremblay, Paul G Serenson, "The Theory and Practice of Compiler Writing", BS Publications, 2005.
2. C. N. Fischer and R. J. LeBlanc, “Crafting a compiler with C”, Benjamin Cummings, 2003.
3. HenkAlblas and Albert Nymeyer, “Practice and Principles of Compiler Building with C”, PHI, 2001.
4. Kenneth C. Louden, “Compiler Construction: Principles and Practice”, Thompson Learning, 2003.
5. Dhamdhere, D. M., "Compiler Construction Principles and Practice", Macmillan India Ltd, 2008

Course Content (Syllabus):

Module I: INTRODUCTION AND LEXICAL ANALYSIS (13 hours) [COMPREHENSION]

Compilers – Cousins of the Compiler - Phases of a compiler - Analysis of the source program - Grouping of phases – Compiler construction tools – Lexical Analysis – Role of the Lexical Analyzer – Input buffering – Specification of tokens – Recognizer - Introduction to LEX Programming.

Module II: SYNTAX ANALYSIS (15 hours) [APPLICATION]

Role of the parser - Top-down parsing - Recursive decent parser - Predictive parser - Bottom-up parsing – Shift reduce parser - LR parser – SLR parser – Canonical parser – LALR parser - YACC programming.

Module III: SEMANTIC ANALYSIS AND INTERMEDIATE CODE GENERATION (14 hours) [APPLICATION]

Introduction to syntax directed translation - Synthesis and inherited attributes - Type Checking - Type Conversions - Intermediate languages – Three address statements - Declarations – Assignment Statements – Boolean Expressions – Case Statements – Back patching – Looping statements - Procedure calls.

Module IV: CODE OPTIMIZATION AND CODE GENERATION (12 hours) [COMPREHENSION]

Basic Blocks and Flow Graphs – Principal sources of optimization – Peephole optimization - Optimization of basic Blocks - DAG representation of Basic Blocks - Issues in the design of code generator – A simple code generator.

Course Outcomes:

On successful completion of the course the students shall be able to:

CO1: Explain the various phases of compiler (COMPREHENSION)

CO2: Apply parsing techniques to check the syntax of given statement. (APPLICATION)

CO3: Produce intermediate code for the given statement. (APPLICATION)

CO4: Discuss how to optimize the given problem for back end of the compiler (COMPREHENSION)

Program Outcomes

PO1 Engineering Knowledge:
Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems. [**High]**

PO2 Problem Analysis:
Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences. **[High]**

PO3 Design/development of Solutions:
Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations. (High]

PO4 Conduct Investigations of Complex Problems:
Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions**.[High**]

PO5 Modern Tool usage:
Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations. **[Moderate]**

PO10 Communication:
Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions. **[Low]**

Mapping of CO with PO

CO / PO N0.	PO1	PO2	PO3	PO4	PO5	PO10
CO1	H	M	M	M	M	L
CO2	H	H	H	H	M	L
CO3	H	H	H	H	-	L
CO4	H	H	M	M	-	L

Course Prerequisites

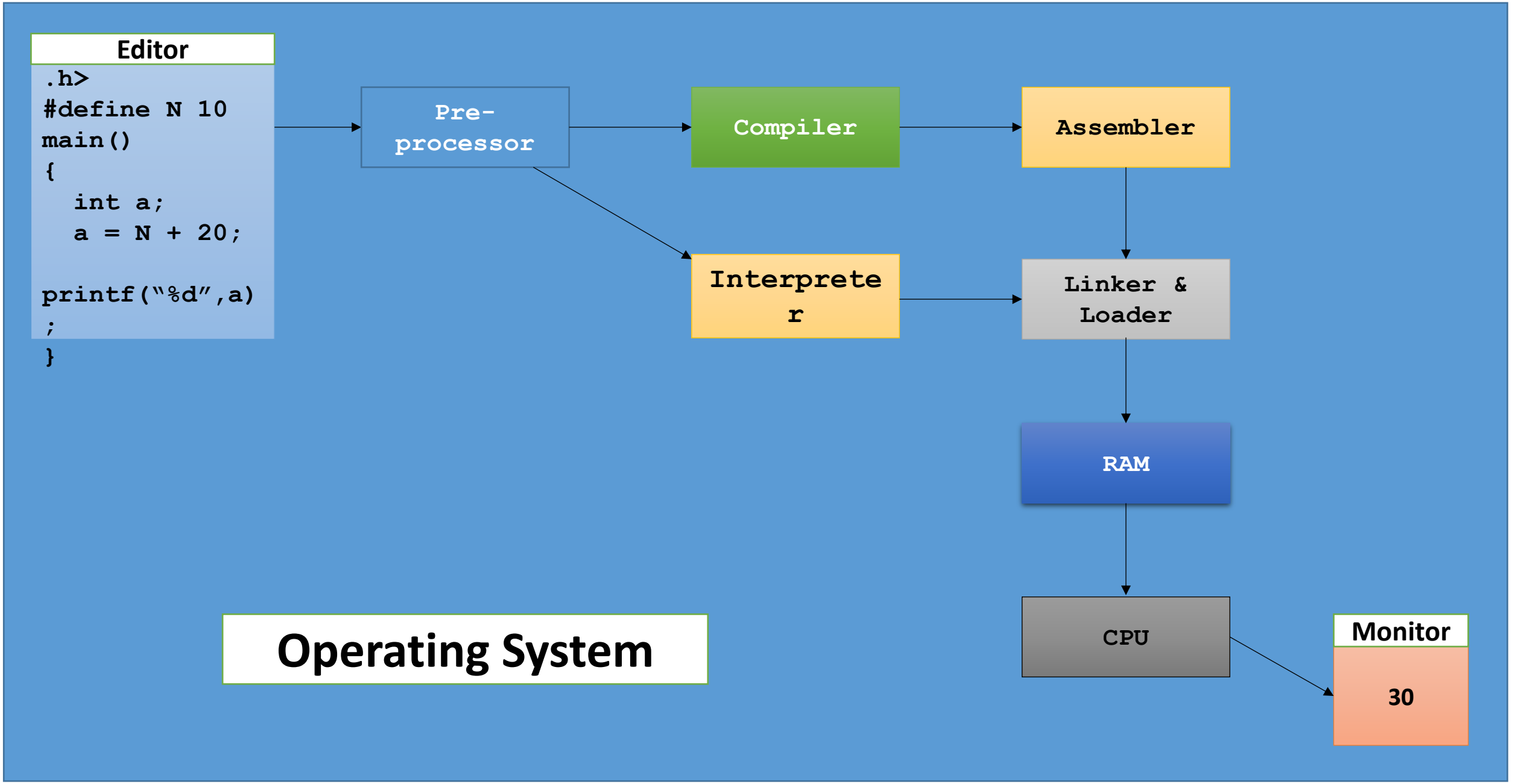
- Finite Automata, Context Free Grammar

  (CSE208 - Theory of Computation – CSE 5th Semester Course)

- System software

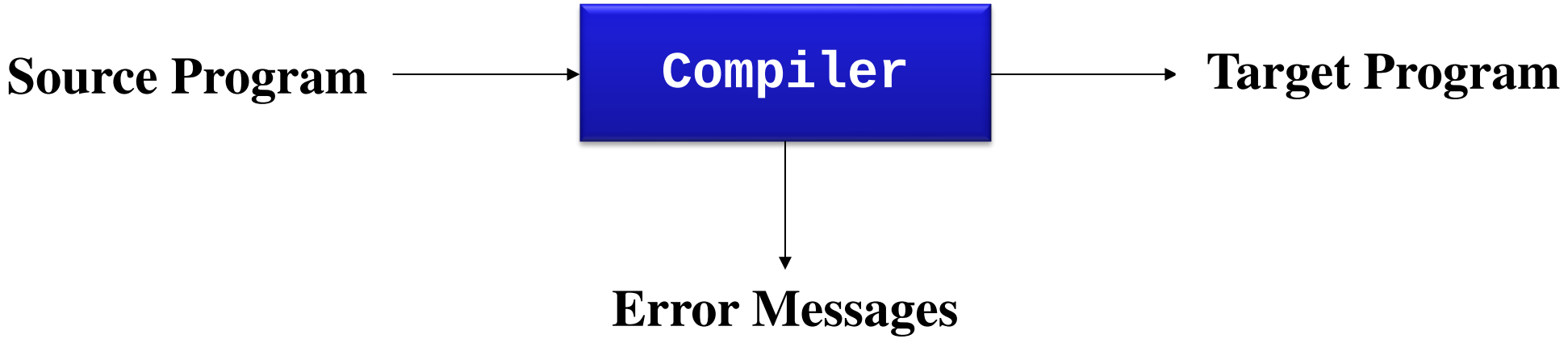
```
#include<stdio
.h>
#define N 10
main()
{
  int a;
  a = N + 20;

printf("%d",a)
;
}
```

Monitor
30


Editor
.h>
#define N 10
main()
{
int a;
a = N + 20;
printf("%d",a)
;
}
Pre-
processor
Compiler
Assembler
Interprete
r
Linker &
Loader
RAM
CPU
Monitor
30
Operating System

COMPILER

- Compiler is a program that reads a program written in one language (source language) and translates it into an equivalent program in another language (the target language).
- As an important part of this translation process, the compiler reports to its user the presence of errors in the source program.



- Source code
  - written in a high level programming language

```
//simple example
while (sum < total)
{
  sum = sum + x*10;
}
```

- Target code
  - Assembly language which in turn is translated to machine code

```
L1: MOV   total,R0
    CMP   sum,R0
    CJ<   L2
    GOTO  L3
L2: MOV   #10,R0
    MUL   x,R0
    ADD   sum,R0
    MOV   R0,sum
    GOTO L1
L3: First Instruction following
    the while statement
```

Why build compilers?

•Programming languages are notations for describing computations to people and to machines. The world as we know it depends on programming languages, because all the software running on all the computers was written in some programming language. But, before a program can be run, it first must be translated into a form in which it can be executed by a computer.

•Compilers provide an essential interface between applications and architectures

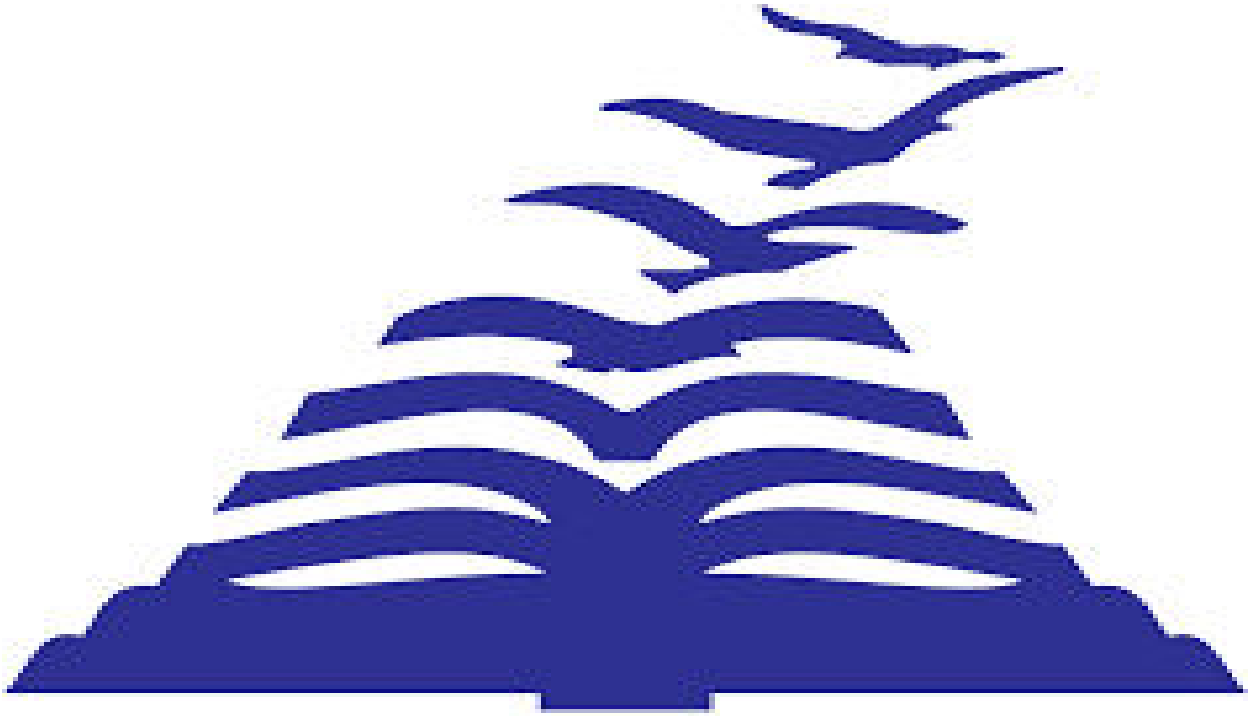
• Compilers efficiently bridge the gap and shield the application developers from low level machine details

Why study compilers?

- Compilers embody a wide range of theoretical techniques and their application to practice
  - DFAs, PDAs, formal languages, formal grammars, fix points algorithms, lattice theory, etc…
- Compiler construction teaches programming and software engineering skills
- Compiler construction involves a variety of areas
  - theory, algorithms, systems, architecture
- **Is compiler construction a solved problem?**
  - No! New developments in programming languages and machine architectures (processors) present new challenges

Desirable Properties of Compilers

- **Compiler must generate a correct executable**
  - The input program and the output program must be equivalent, the compiler should preserve the meaning of the input program
- **Output program should run fast**
  - For optimizing compilers we expect the output program to be more efficient than the input program
- **Compiler should provide good diagnostics for programming errors**
- **Compiler should work well with debuggers**
- **Compile time should be proportional to code size**



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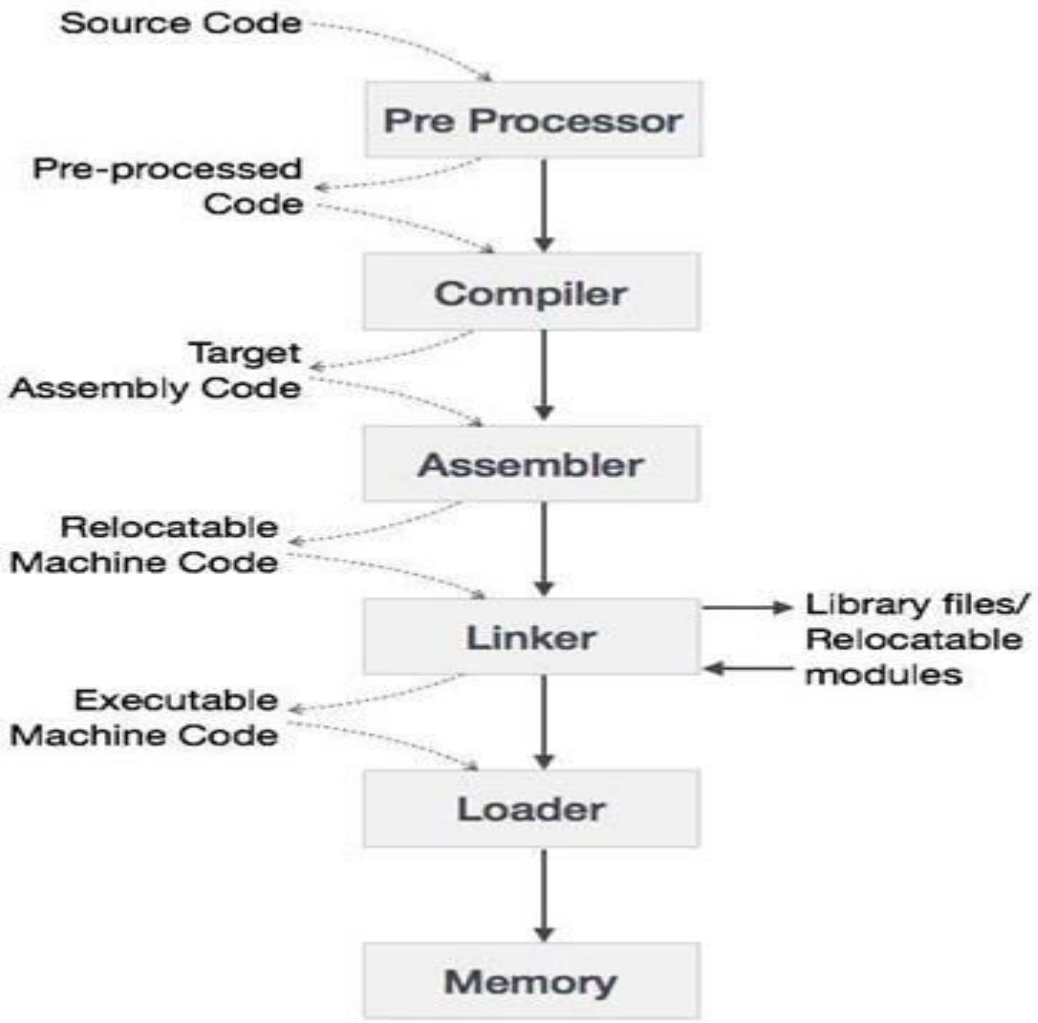
COUSINS OF COMPILER

COUSINS OF COMPILER

The input to a compiler may be processed by one or more preprocessors, and further processing of the compiler's output may be needed before running machine code is obtained.



Cousins of Compiler are

1. **Preprocessor**
2. **Assembler**
3. **Loader and Link-editor**

Preprocessor

- A preprocessor is a program that processes its input data **(Source Program with Preprocessing Statements)** to produce output **(Source Program without Preprocessing Statements)** that is used as input to another program **(Compilers).**

They may perform the following functions :

1. **Macro processing**
2. **File Inclusion**
3. **Rational Preprocessors**
4. **Language extension**

1. Macro processing:

A Preprocessor may allow a user to define macros are shorthands for longer constructs.

2. File Inclusion:

Preprocessor includes header files into the program text. When the preprocessor finds an #include directive it replaces it by the entire content of the specified file.

3. Rational Preprocessors:

These processors change older languages with more modern flow-of-control and data- structuring facilities.

4. Language extension :

These processors attempt to add capabilities to the language by what amounts to built-in macros. For example, the language Equel is a database query language embedded in C.

Assembler

Assembler creates object code by translating assembly instruction mnemonics into machine code.

There are two types of assemblers:

- One-pass assemblers go through the source code once and assume that all symbols will be defined before any instruction that references them.
-
- Two-pass assemblers create a table with all symbols and their values in the first pass, and then use the table in a second pass to generate code

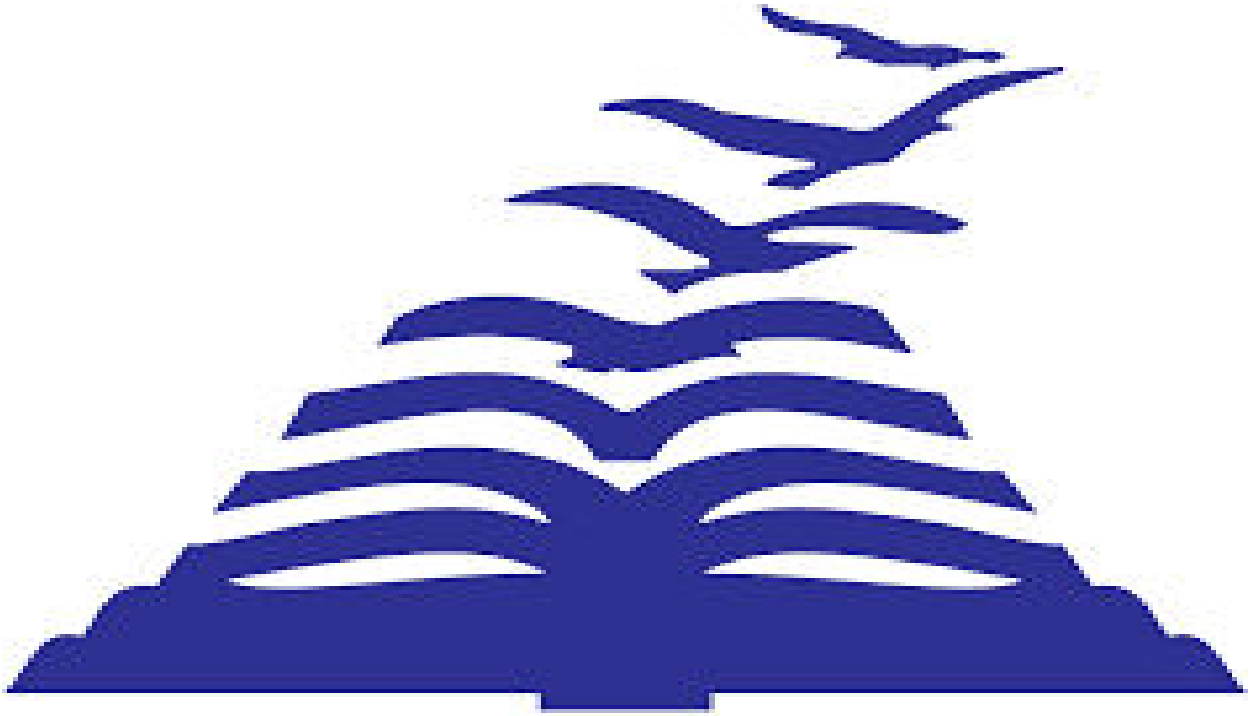
Linker and Loader

A **linker** or **link editor** is a program that takes one or more objects generated by a compiler and combines them into a single executable program.

Three tasks of the linker are

1. Searches the program to find library routines used by program, e.g. printf(), math routines.
2. Determines the memory locations that code from each module will occupy and relocates its instructions by adjusting absolute references
3. Resolves references among files.

A **loader** is the part of an operating system that is responsible for loading executable programs into permanent memory for execution.



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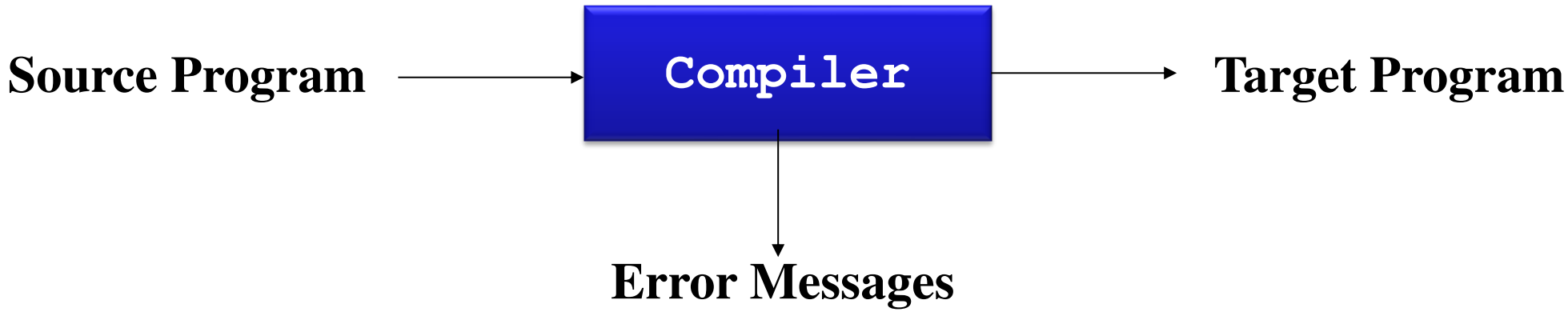
PHASES OF COMPILER

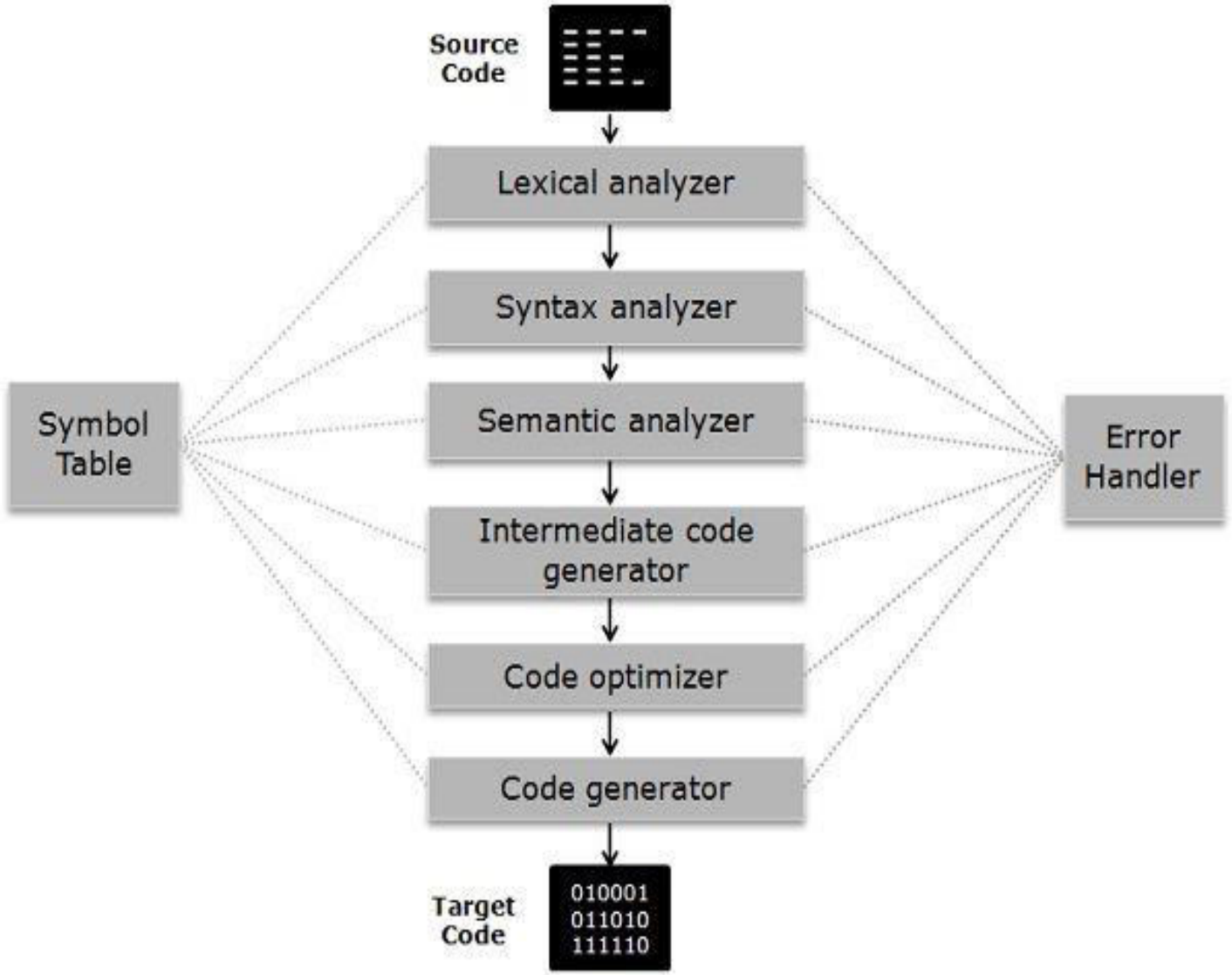
COMPILER

- Compiler is a program that reads a program written in one language (source language) and translates it into an equivalent program in another language (the target language).
- As an important part of this translation process, the compiler reports to its user the presence of errors in the source program.



Phases of a Compiler

Conceptually, a compiler operates in ***phases***, each of which transforms the source program from one representation to another.



Lexical Analysis

- The first phase of a compiler is called lexical analysis or **scanning**. It is also called as **linear analysis**.

- The lexical analyzer reads the stream of characters making up the source program and groups the characters into meaningful sequences called lexemes.

- For each lexeme, the lexical analyzer produces as output a token of the form
  (token-name, attribute-value)
  that it passes on to the subsequent phase, syntax analysis.

- In the token, the first component token-name is an abstract symbol that is used during syntax analysis, and the second component attribute-value points to an entry in the symbol table for this token.

- Information from the symbol-table entry is needed for semantic analysis and code generation.

Lexical Analysis

For example, suppose a source program contains the assignment statement

position = initial + rate * 60

1. **position** is a lexeme that would be mapped into a **token (id, 1)**, where id is an abstract symbol standing for identifier and 1 points to the symbol table entry for position. The symbol-table entry for an identifier holds information about the identifier, such as its name and type.
2. The **assignment symbol = is a lexeme** that is mapped into the token (=). Since this token needs **no attribute-value**.
3. **initial** is a lexeme that is mapped into the token **(id, 2)**, where 2 points to the symbol-table entry for initial .
4. **+** is a lexeme that is mapped into the **token (+)**.
5. **rate** is a lexeme that is mapped into the **token (id, 3)**, where 3 points to the symbol-table entry for rate .
6. ***** is a lexeme that is mapped into the **token (*).**
7. **60 is a lexeme** that is mapped into the token (number type,value). ➔ (Integer, 60)

Lexical Analysis

position = initial + rate * 60

(id,1) = (id,2) + (id,3) * (number,60)

For understanding easier and for our convenience, We can write this as

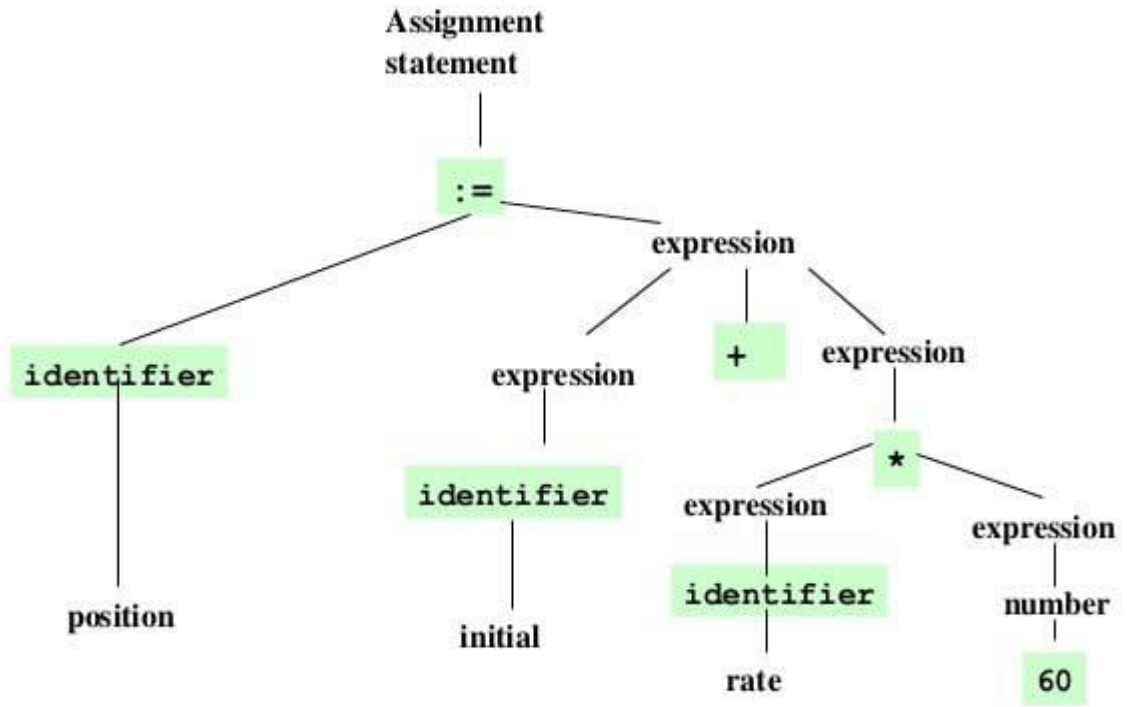
id1 = id2 + id3 * 60

Syntax Analysis

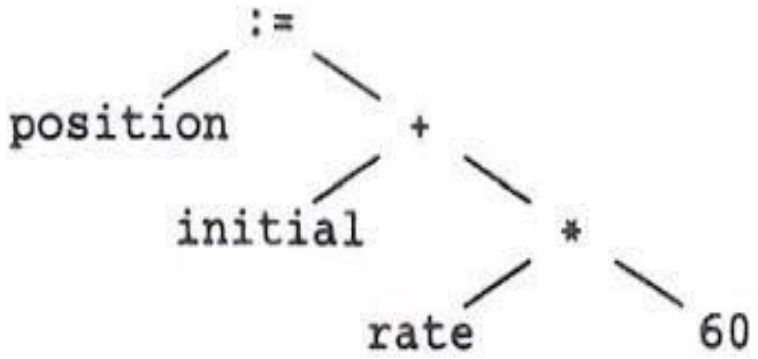
- The second phase of the compiler is **syntax analysis or parsing**.
- The parser uses the first components of the tokens produced by the lexical analyzer to create a tree-like intermediate representation that depicts the grammatical structure of the token stream.
- A typical representation is a **syntax tree** in which each interior node represents an operation and the children of the node represent the arguments of the operation.

Parse tree

position : = initial + rate * 60



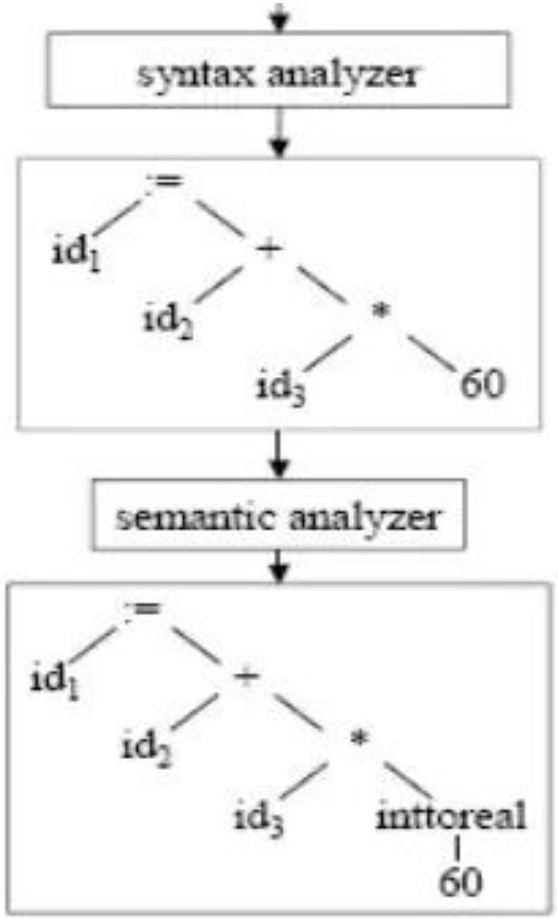
Syntax Tree

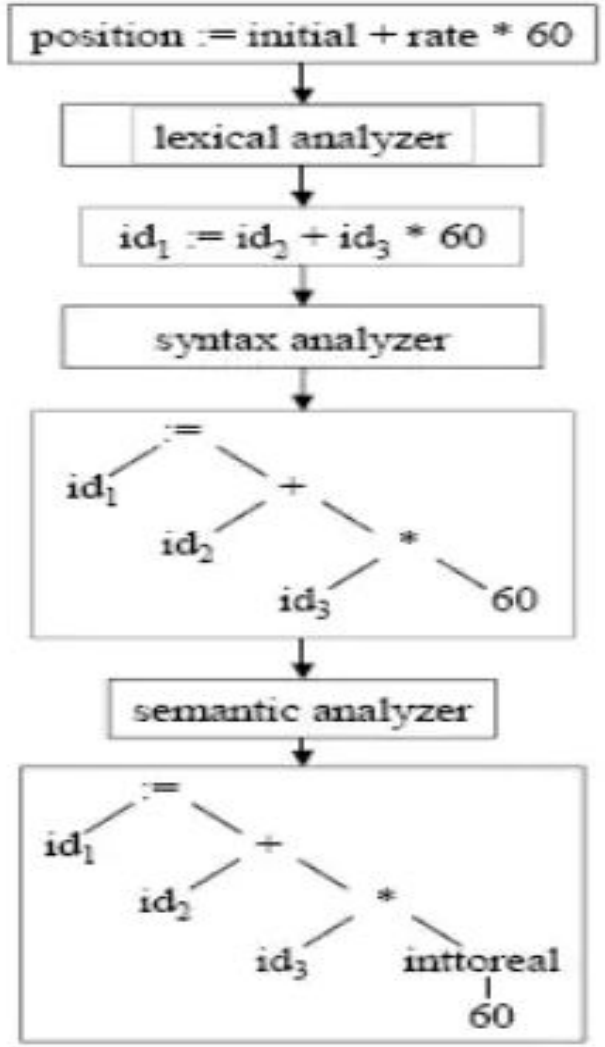


Semantic Analysis

- The semantic analyzer uses the syntax tree and the information in the symbol table to check the source program for semantic consistency with the language definition.
- It also gathers type information and saves it in either the syntax tree or the symbol table, for subsequent use during intermediate-code generation.
- An **important part of semantic analysis is type checking**, where the compiler checks that each operator has matching operands.
- For example, many programming language definitions require an array index to be an integer; the compiler must report an error if a floating-point number is used to index an array.

Semantic Analysis





Semantic Analysis

- The language specification may permit some type conversions called coercions. (Conversion from one type to another is said to be implicit if it is to be done automatically by the compiler. Implicit type conversions, also called Coercions (no information is lost in principle).

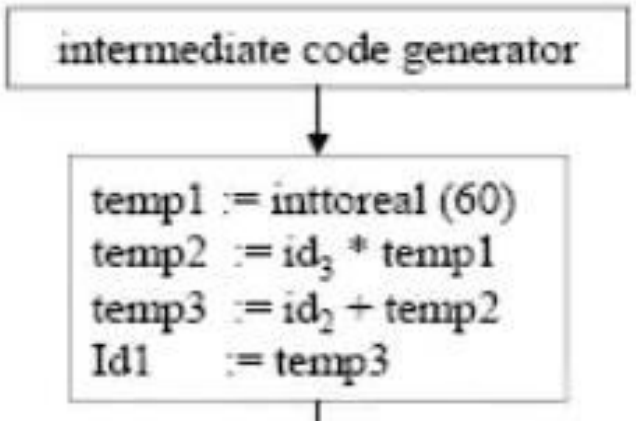
```
int b;
float a;
a = b;
```

- Conversion is said to be explicit if the programmer must write something to cause the conversion.

```
int b;
float a;
a = (int) b;
```

Intermediate Code Generation

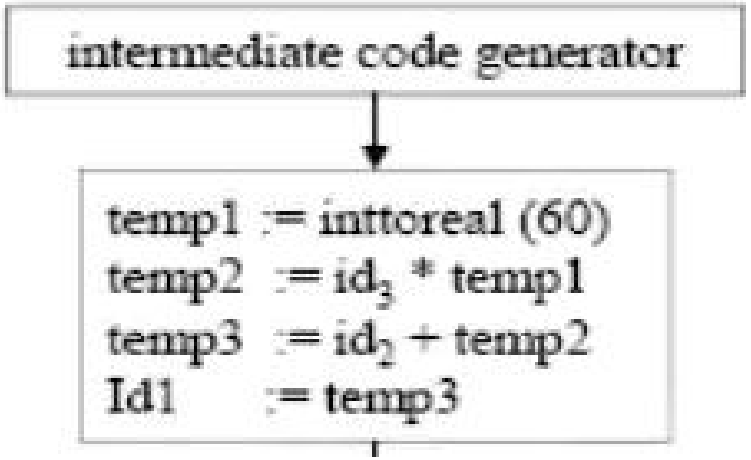
- After syntax and semantic analysis of the source program, many compilers generate an explicit low-level or machine-like intermediate representation.
- In the process of translating a source program into target code, a compiler may construct one or more intermediate representations, which can have a variety of forms.
- This intermediate representation should have two important properties: it should be easy to produce and it should be easy to translate into the target machine



Intermediate Code Generation

- One of the mostly used intermediate form called **three-address code**, which consists of a sequence of assembly-like instructions with three operands per instruction.

- Three-address instruction has several important properties:
  - First, each three-address assignment instruction has at most one operator on the right side.
  - Second, the compiler must generate a temporary name to hold the value computed by a three-address instruction.
  - Third, some three-address instructions have fewer than three operands.

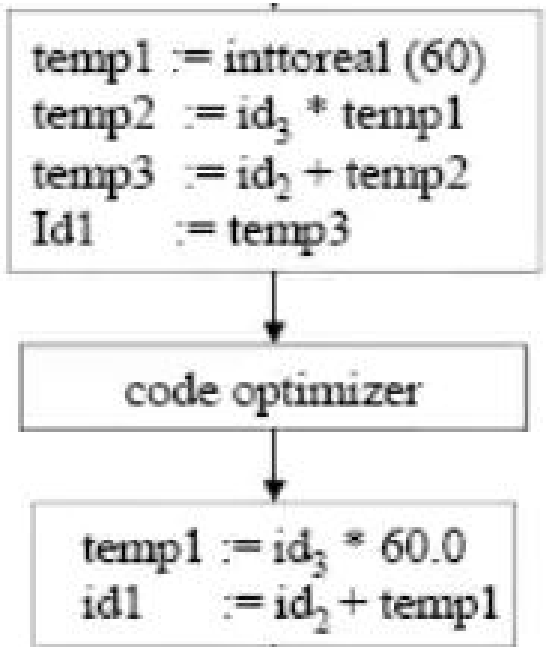


Code Optimization

- The machine-independent code-optimization phase attempts to improve the intermediate code so that **better target code will result**. Usually better means **faster**, but other objectives may be desired, such as shorter code, or target code that **consumes less power**.

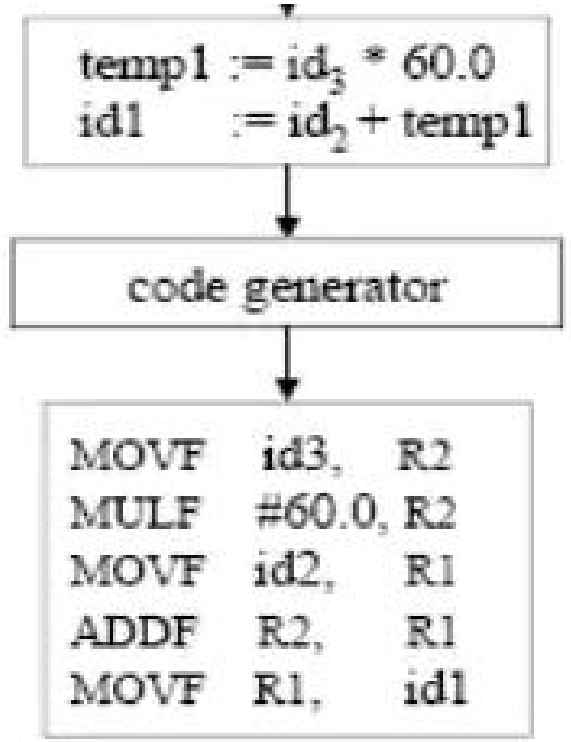
- There is a great variation in the amount of code optimization different compilers perform.

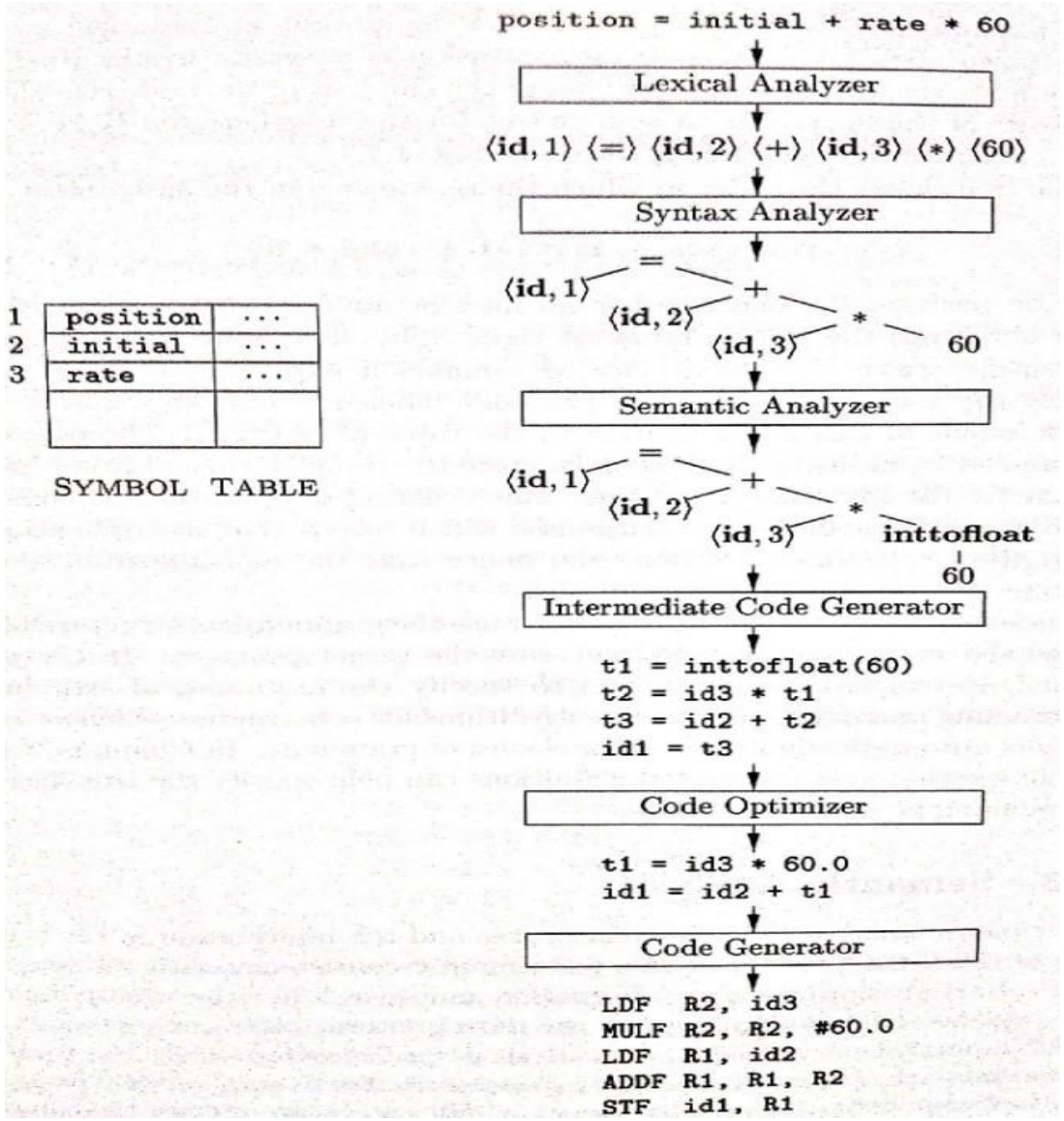
- **Optimizing compilers** spent a significant amount of time is spent on this phase. There are simple optimizations that significantly improve the running time of the target program without slowing down compilation too much.



Code Generation

- Final phase of the compiler is generation of target code, consisting normally of **relocatable machine code or assembly code.**
- Memory locations are selected for each of the variables used by the program.
- Then, the intermediate instructions are translated into sequences of machine instructions that perform the same task.
- A crucial aspect of code generation is the judicious assignment of registers to hold variables.




position = initial + rate * 60
Lexical Analyzer
⟨id, 1⟩ ⟨=⟩ ⟨id, 2⟩ ⟨+⟩ ⟨id, 3⟩ ⟨*⟩ ⟨60⟩
Syntax Analyzer
Semantic Analyzer
inttofloat
Intermediate Code Generator
t1 = inttofloat(60)
t2 = id3 * t1
t3 = id2 + t2
id1 = t3
Code Optimizer
t1 = id3 * 60.0
id1 = id2 + t1
Code Generator
LDF R2, id3
MULF R2, R2, #60.0
LDF R1, id2
ADDF R1, R1, R2
STF id1, R1
1 position ...
2 initial ...
3 rate ...
SYMBOL TABLE

Symbol Table Management

- An essential function of a compiler is to record the variable names used in the source program and collect information about various attributes of each name. These attributes may provide information about the storage allocated for a name, its type, its scope (where in the program its value may be used), and in the case of procedure names, such things as the number and types of its arguments, the method of passing each argument (for example, by value or by reference), and the type returned.

- The **symbol table is a data structure** containing a record for each variable name, with fields for the attributes of the name.

- The data structure should be designed to allow the compiler to **find the record for each name quickly and to store or retrieve data from that record quickly.**

Symbol Table Management

Symbol Table for Identifiers (Variables)

Name of the Symbol	Location	Type	Scope	Value	Size	…

Symbol Table for Identifiers (Functions)

Name of the Symbol	No. of Arguments	Type of Arguments	Scope	Return type	…

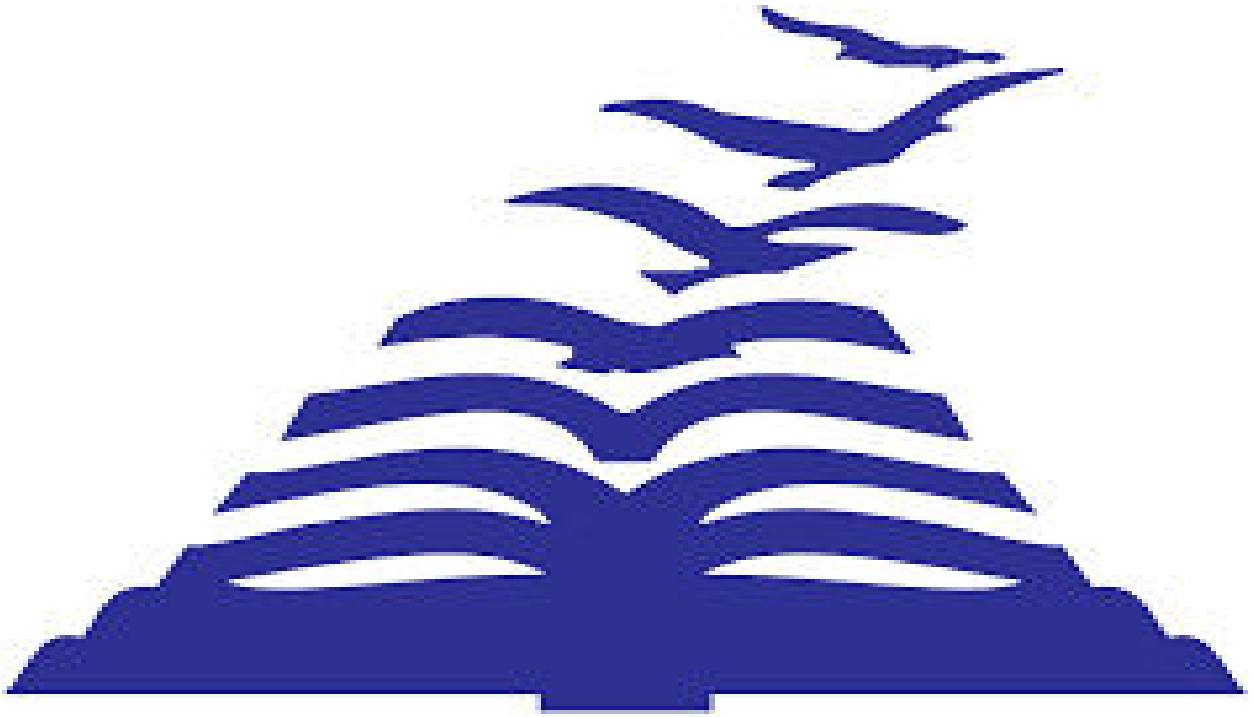
Error Detection and Reporting

- Each phase can encounter Errors. However, after detecting an error, a phase must somehow deal with that error, so that compilation can proceed, allowing further errors in the source program to be detected.

- The syntax and semantic analysis phases usually handle a large fraction of the errors detectable by the compiler.

Some Errors in Phases of Compiler

- ❑ Lexical analyzer: Wrongly spelled tokens
- ❑ Syntax analyzer: Missing parenthesis
- ❑ Semantic analyzer: Mismatched operands for an operator
- ❑ Intermediate code generator: When the memory is full when generating temporary variables
- ❑ Code Optimizer: When the statement is not reachable
- ❑ Code Generator: When the memory is full or proper registers are not allocated



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Analysis of the Phases and Grouping of Phases

Analysis of the Phases

Compilation Process is divided into two parts:

- **Analysis and**
- **Synthesis**

- The analysis part breaks up the source program into constituent pieces and imposes a grammatical structure on them.
- It then uses this structure to create an intermediate representation of the source program.
- If the analysis part detects that the source program is either syntactically ill formed or semantically unsound, then it must provide informative messages, so the user can take corrective action.
- The analysis part also collects information about the source program and stores it in a data structure called a symbol table, which is passed along with the intermediate representation to the synthesis part.

- The synthesis part constructs the desired target program from the intermediate representation and the information in the symbol table.

- The **analysis part** is often called the **front end of the compiler**; the **synthesis part** is the **back end**.

Grouping of Phases into Passes

Front End and Back End

- The **analysis part** is often called the **front end of the compiler**; the **synthesis part** is the **back end**.
- The discussion of **phases** deals with the **logical organization** of a compiler.
- In an implementation, activities from **several phases may be grouped together into a pass** that reads an input file and writes an output file.

Front End

- For example, the **front-end phases of lexical analysis, syntax analysis, semantic analysis, and intermediate code generation** might be grouped together into one pass.
- **Frond ends** are **depends primarily** on **source language** and are largely independent of the target machine.

Back End

- The **back end** includes those portions of the compiler that **depend on the target machine**, and generally, these portions do **not depend on the source language, just the intermediate language**.

- **Code optimization** might be an **optional pass**. Then there could be a back-end pass consisting of **code generation** for a particular target machine.

Some compiler collections have been created around carefully designed **intermediate representations** that allow the front end for a particular language to interface with the back end for a certain target machine.

With these collections, **we can produce compilers for different source languages for one target machine** by combining different front ends with the back end for that target machine.

Similarly, **we can produce compilers for different target machines**, by combining a front end with back ends for different target machines.

Passes

Several phases of compilation are implemented in a single pass consisting of reading an input file and writing an output file.

Reducing the number of passes

- Takes time to read and write intermediate files.
- Grouping of several phases into one pass, may force the entire program in memory, because one phase may need information in a different order than previous phase produces it.
- Intermediate code and code generation are often merged into one pass using a technique called backpatching.

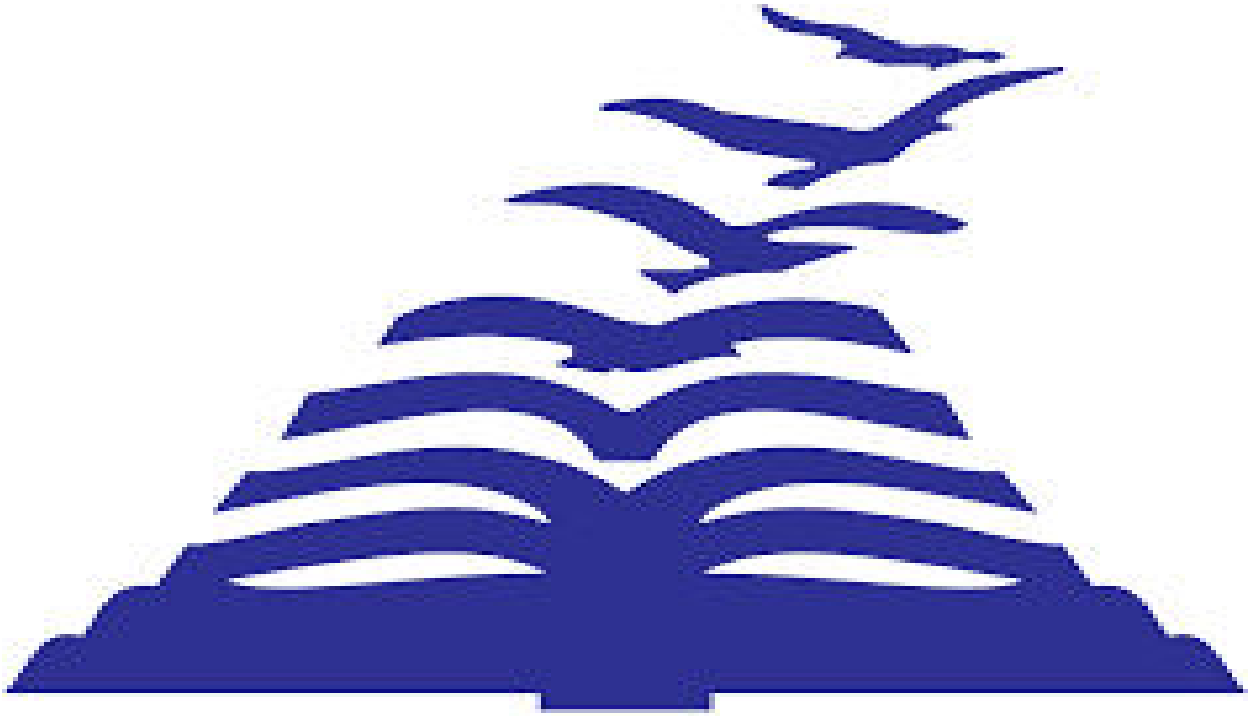
For some phases, grouping into single pass presents few problems.

For example, the interface between lexical and syntax analyzers can often limited into single token.

On the other hand, it is often very hard to perform code generation until the intermediate representation has been completely generation.

To avoid these issues, **Backpatching** is used.

In some cases, it is possible to leave a blank slot for missing information, and fill in the slot when the information become available. This is called as "Backpatching".



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Compiler Construction Tools

Compiler Construction Tools

The compiler writer, like any **software developer, can profitably use** modern software development environments containing tools such as **language editors, debuggers, version managers, profilers, test harnesses**, and so on.

Shortly after the **first compilers were written**, systems to help with the compiler-writing process appeared. These systems have often been referred to as **Compiler-Compilers, Compiler-Generators** or **Translator-Writing Systems.**

Some general tools have been created for the **automatic design of specific compiler** components. These tools use specialized languages for specifying and implementing the component, and also many use sophisticated algorithms.

The most successful tools produce components that can be easily integrated into the remainder of a compiler.

Compiler Construction Tools

The following is a list of some useful compiler-construction tools:

- **Parser Generators**
- **Scanner Generators**
- **Syntax-directed Translation Engines**
- **Automatic Code Generators**
- **Data-flow Analysis Engines**

Compiler Construction Tools

- **Scanner Generators**

  This tool **automatically generate lexical analyzers**, normally from a specification based on **regular expressions**. The basic organization of the resulting lexical analyzers is in effect a **finite automaton**.

- **Parser Generators**

  These tools produce **syntax analyzers**, normally from input that is based on a **Context-Free Grammar (CFG)**. In early compilers, syntax analysis consumed not only a large fraction of the compilation time, but a large fraction of the intellectual effort of writing a compiler. **Many parser generator utilize powerful parsing algorithm that are too complex.**

Compiler Construction Tools

- **Syntax-directed Translation Engines**

  These tools produce **collections of routines** for walking a parse tree and **generating intermediate code**. The basic idea is that one or more "translation" are associated with each node of the parse tree, and each translation is defined in terms of translations at its neighbor nodes in the tree.

- **Automatic Code Generators**

  These tools **produce a code generator** from a **collection of rules** for translating each operation of the **intermediate language into the machine language for a target machine**. The rules must include sufficient details that we can handle the different possible access methods for data. For example **variable may be in register or fixed (static) location or may be in stack.**

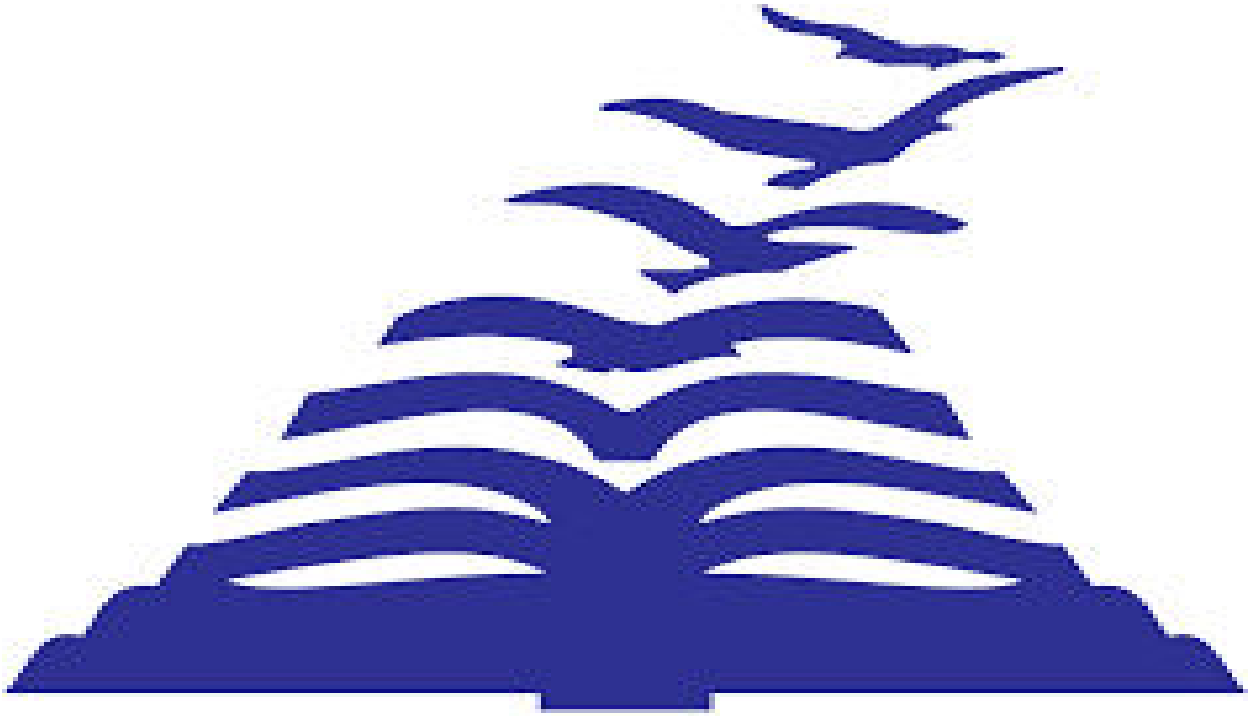
  The basic technique is "Template Matching" – The intermediate code statements are replaced by "templates" that represent sequences of machine instruction.

Compiler Construction Tools

- **Data-flow Analysis Engines**

  Much of the information needed to perform **good code optimization** involves "**Data-Flow Analysis**", the gathering of information about how values are transmitted from one part of a program to each other part.

  Data-flow analysis is a **key part of code optimization**.



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Lexical Analysis

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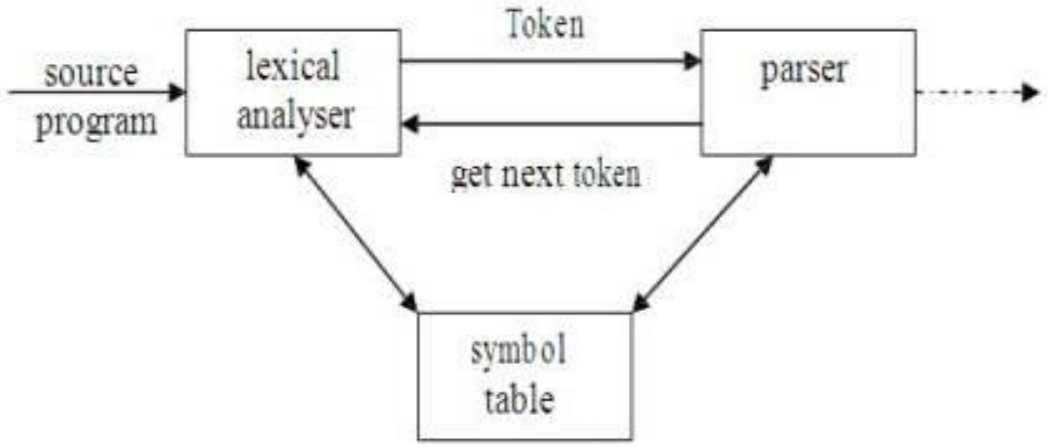
Role and Need of Lexical Analysis

The Role of the Lexical Analyzer

- As the first phase of a compiler, the main task of the lexical analyzer is to read the input characters of the source program, group them into lexemes, and produce as output a sequence of tokens for each lexeme in the source program.
- The stream of tokens is sent to the parser for syntax analysis.
- It is common for the lexical analyzer to interact with the symbol table as well.
- When the lexical analyzer discovers a lexeme constituting an identifier, it needs to enter that lexeme into the symbol table.



The Role of the Lexical Analyzer

Issues in Lexical Analysis

There are a number of reasons why the analysis portion of a compiler is normally separated into lexical analysis and parsing (syntax analysis) phases.

1. **Simplicity of design is the most important consideration.**

   The separation of lexical from syntax analysis often allows us to simplify at least one or the other of these phases. (For example, Stripping out comments and white spaces is somewhat easy job by lexical analyzer than syntax analyzer).

2. **Compiler efficiency is improved.**

   A separate lexical analyzer allows us to apply specialized techniques that serve only the lexical task, not the job of parsing. In addition, specialized buffering techniques for reading input characters can speed up the compiler significantly.

3. **Compiler portability is enhanced.**

   Input-device-specific peculiarities can be restricted to the lexical analyzer. (For example, ↑ in pascal)

The Role of the Lexical Analyzer

Lexical Analyzer also performs certain secondary task

- Stripping out comments and whitespace (blank, newline, tab) in the source program.
- Correlating error messages generated by the compiler with the source program.

Sometimes, lexical analyzers are divided into a cascade of two processes:

- **Scanning** consists of the simple processes that do not require tokenization of the input, such as deletion of comments and compaction of consecutive whitespace characters into one.
- **Lexical analysis** proper is the more complex portion, where the scanner produces the sequence of tokens as output.

The Role of the Lexical Analyzer

Tokens, Patterns, and Lexemes

When discussing lexical analysis, we use three related but distinct terms:

Token

- A token is a pair consisting of a token name and an optional attribute value.
- The token name is an abstract symbol representing a kind of lexical unit (Keyword, Identifier, Operator…)

Pattern

- The set strings is described by a rule called a pattern associated with the token.

Or

- A pattern is a rule describing the set of lexemes that can represent a particular token in source programs.

Lexeme

- A lexeme is a sequence of characters in the source program that matched by the pattern for a token.

The Role of the Lexical Analyzer

Pattern	Token	Lexeme
while, for, if, else, int	Keyword	while | for | if | else | int
Letter followed by zero or more instance of Letter or Digit	Identifier	a, mark1, length, emp123, s567
Digit followed by zero of more instance of Digit	Number	79, 22, 4, 2021, 123456
Any symbols between “ and “ except “	Literal or String	“Welcome”, “Presidency University”, “Bengaluru”

1. One token for each keyword. The pattern for a keyword is the same as the keyword itself.
2. Tokens for the 1 operators, either individually or in classes.
3. One token representing all identifiers.
4. One or more tokens representing constants, such as numbers and literal strings
5. Tokens for each punctuation symbol, such as left and right parentheses, comma, and semicolon.

The Role of the Lexical Analyzer

Attributes for Tokens

- When more than one lexeme can match a pattern, the lexical analyzer must provide the subsequent compiler phases additional information about the particular lexeme that matched.
- For example, the pattern for token number matches both 0 and 1, but it is extremely important for the code generator to know which lexeme was found in the source program.
- Thus, in many cases the lexical analyzer returns to the parser not only a token name, but an attribute value that describes the lexeme represented by the token;
- The token name influences parsing decisions, while the appropriate attribute value for an identifier is a pointer to the symbol-table entry for that identifier.

<Token Name, Attribute-Value>

<Identifier, 2001> <Number, 123> <IF> <+> <{>

The Role of the Lexical Analyzer

Lexical Error

- It is hard for a lexical analyzer to tell source-code error.
- For instance, if the string **whiel** is encountered for the first time in a C program in the context:

  whiel (Mark >= 90)

  a lexical analyzer cannot tell whether **whiel** is a misspelling of the keyword **while** or an undeclared function identifier. Since **whiel** is a **valid lexeme** for the token id, the lexical analyzer must return the token id to the parser.
- However, suppose a situation arises in which the lexical analyzer is **unable to proceed** because **none of the patterns for tokens matches any prefix** of the remaining input. The **simplest recovery strategy** is "**panic mode**" recovery.
- In Panic Mode, We delete successive characters from the remaining input, until the lexical analyzer can find a well-formed token.

The Role of the Lexical Analyzer

Lexical Error

Other possible error-recovery actions are:

1. Delete one character from the remaining input.
2. Insert a missing character into the remaining input.
3. Replace a character by another character.
4. Transpose two adjacent characters.

A more general correction strategy is to find the smallest number of transformations needed to convert the source program into one that consists only of valid lexemes, but this approach is considered too expensive in practice to be worth the effort.