Compiler Design - Introduction

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Objectives

- To introduce the major concept areas in compiler design and know the various phases of the compiler
- To understand the various parsing algorithms and comparison of the same
- To provide practical programming skills necessary for designing a compiler
- To gain knowledge about the various code generation principles
- To understand the necessity for code optimization

Syllabus

UNIT I Introduction to Compilation

Compilers - Analysis of the source program - Phases of a compiler - Cousins of the Compiler - Grouping of Phases - Compiler construction tools - Lexical Analysis - Role of Lexical Analyzer - Input Buffering - Specification of Tokens.

Lab Component: Tutorial on LEX / FLEX tool, Tokenization exercises using LEX.

UNIT II Syntax Analysis

Role of the parser - Writing Grammars - Context-Free Grammars - Top Down parsing - Recursive Descent Parsing - Predictive Parsing - Bottom-up parsing - Shift Reduce Parsing - Operator Precedent Parsing - LR Parsers - SLR Parser - Canonical LR Parser - LALR Parser.

Lab Component: Tutorial on YACC tool, Parsing exercises using YACC tool.

UNIT III Intermediate Code Generation

Intermediate languages - Declarations - Assignment Statements - Boolean Expressions - Case Statements - Back patching - Procedure calls.

Lab Component: A sample language like C-lite is to be chosen. Intermediate code generation exercises for assignment statements, loops, conditional statements using LEX/YACC.

UNIT IV Code Optimization and Run Time Environments

Introduction - Principal Sources of Optimization - Optimization of basic Blocks - DAG representation of Basic Blocks - Introduction to Global Data Flow Analysis - Runtime Environments - Source Language issues - Storage Organization - Storage Allocation strategies - Access to non-local names - Parameter Passing - Error detection and recovery.

Lab Component: Local optimization to be implemented using LEX/YACC for the sample language.

UNIT V Code Generation

Issues in the design of code generator - The target machine - Runtime Storage management - Basic Blocks and Flow Graphs - Next-use Information - A simple Code generator - DAG based code generation - Peephole Optimization.

Lab Component: DAG construction, Simple Code Generator implementation, DAG based code generation using LEX/YACC for the sample language.

Course Outcomes

- Apply the knowledge of LEX & YACC tool to develop a scanner and parser
- Design and develop software system for backend of the compiler
- Suggest the necessity for appropriate code optimization techniques
- Conclude the appropriate code generator algorithm for a given source language
- Design a compiler for any programming language

Text Books

- Alfred V. Aho, Jeffrey D Ullman, “Compilers: Principles, Techniques and Tools”, Pearson Education Asia, 2012.
- Jean Paul Tremblay, Paul G Serenson, “The Theory and Practice of Compiler Writing”, BS Publications, 2005.
- Dhamdhere, D. M., “Compiler Construction Principles and Practice”, Second Edition, Macmillan India Ltd., New Delhi, 2008.

History

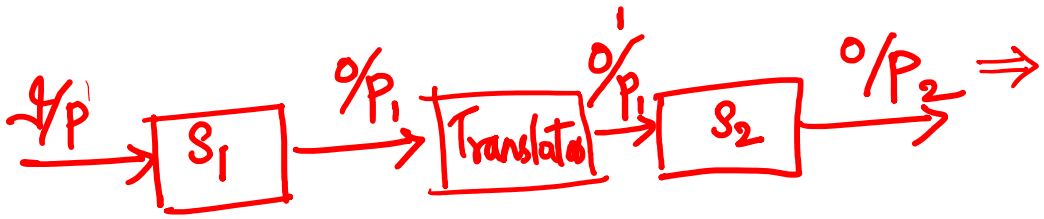
- Software – essential component of the current scenario
- Early software was written in assembly languages
- Drawbacks
  - Very difficult to remember instructions
- The benefits of reusing software on different CPUs became greater than the cost of designing compiler
- Very cumbersome to write
- Need for a software that will understand human language

Language Processors.

- A **translator** inputs and then converts a **source program** into an **object or target** program.

- **Source program** is written in one language
- **Object program** belongs to an object language

- A translators could be: **Assembler, Compiler, Interpreter**



Options

- Design an interpreter / translator to convert human language to machine language
  - Difficult – Parsing, interpreting, ambiguous

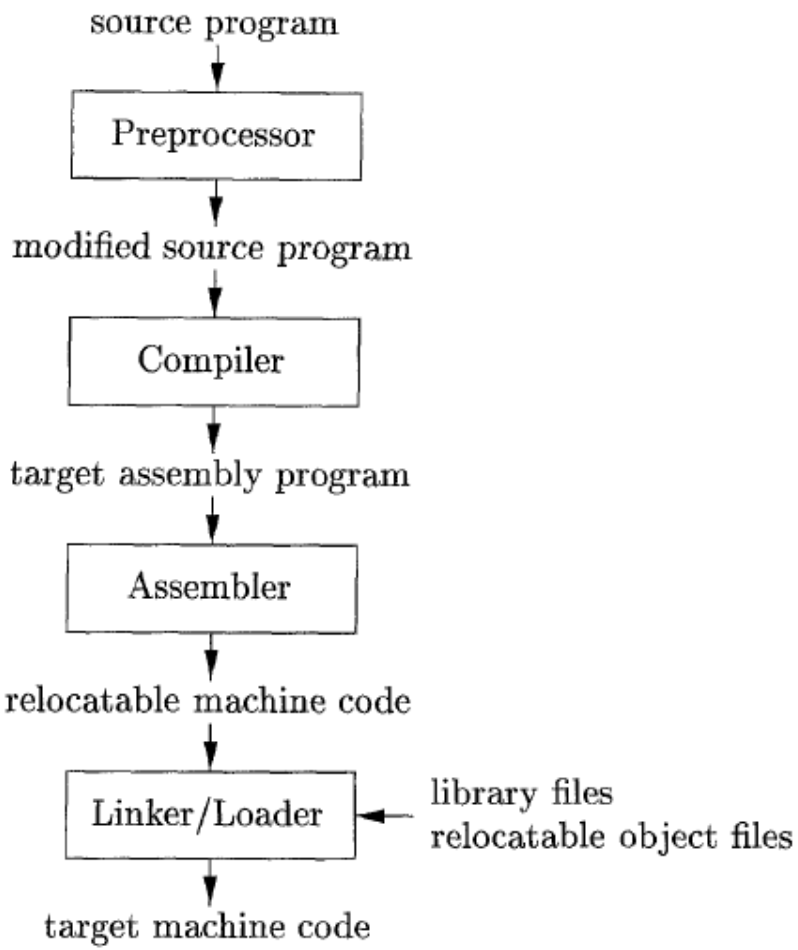
Options

- Design a compiler that will understand high level (not necessary English) language to assembly language
  - Relatively simpler, but need a mapping of the high level language to assembly language

Options

- Design an assembler that converts assembly language to machine language
  - Target language need to be specified. Output of the various compilers to be known prior time

Language Processing System



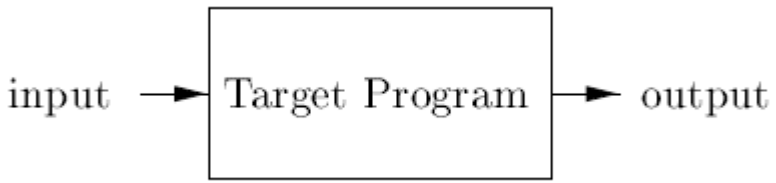
#define MAX 100

Compiler

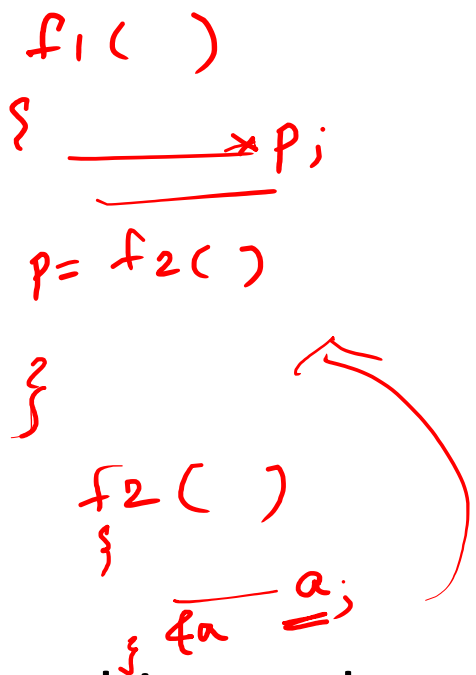
- The first real compiler
  - FORTRAN compilers of the late 1950s
  - 18 person-years to build

What are Compilers?

- A compiler acts as a translator,
  transforming human-oriented programming languages
  into computer-oriented machine languages.
- No concern about machine-dependent details for programmer



Compiler



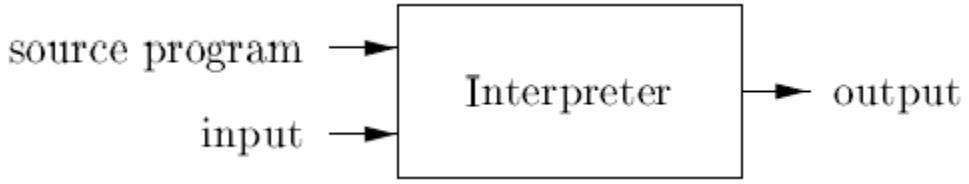
- Processes source program
- Prompts errors in source program
- Recovers / Corrects the errors
- Produce assembly language program
- Compiler + assembler – Converts this to relocatable machine code

Compiler - Overview

- Translates a source program written in a High-Level Language (HLL) such as Pascal, C++ into computer's machine language (Low-Level Language (LLL))
- The time of conversion from source program into object program is called **compile time**
- The object program is executed at **run time**

Interpreter

- Language processor that executes the operation as specified in the source program
- Inputs are supplied by the user
- Processes an internal form of the source program and data at the same time (at run time); no object program is generated.

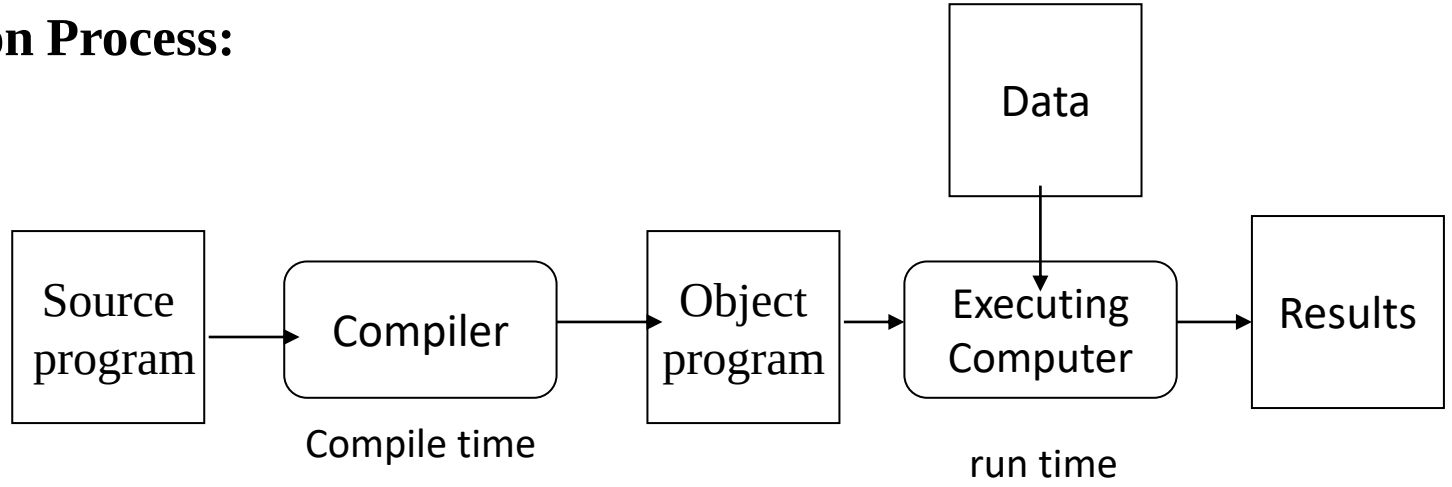


Compiler vs Interpreter

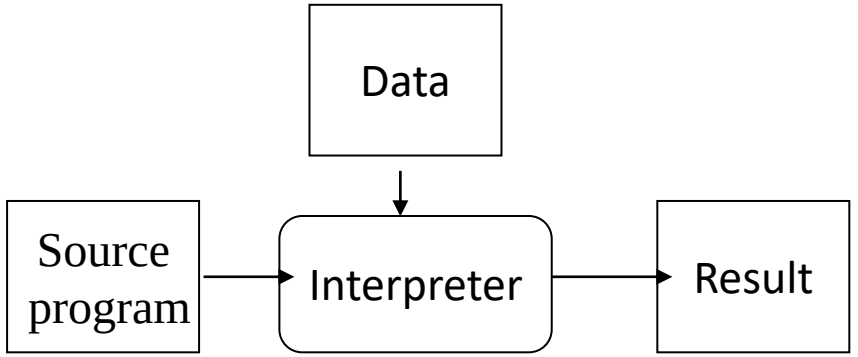
- The machine-language target program produced by a compiler is much faster than an interpreter at mapping inputs to outputs
- An interpreter, is better with error diagnostics as it executes the source program statement by statement

Overview of Compilers

Compilation Process:



Interpretive Process:



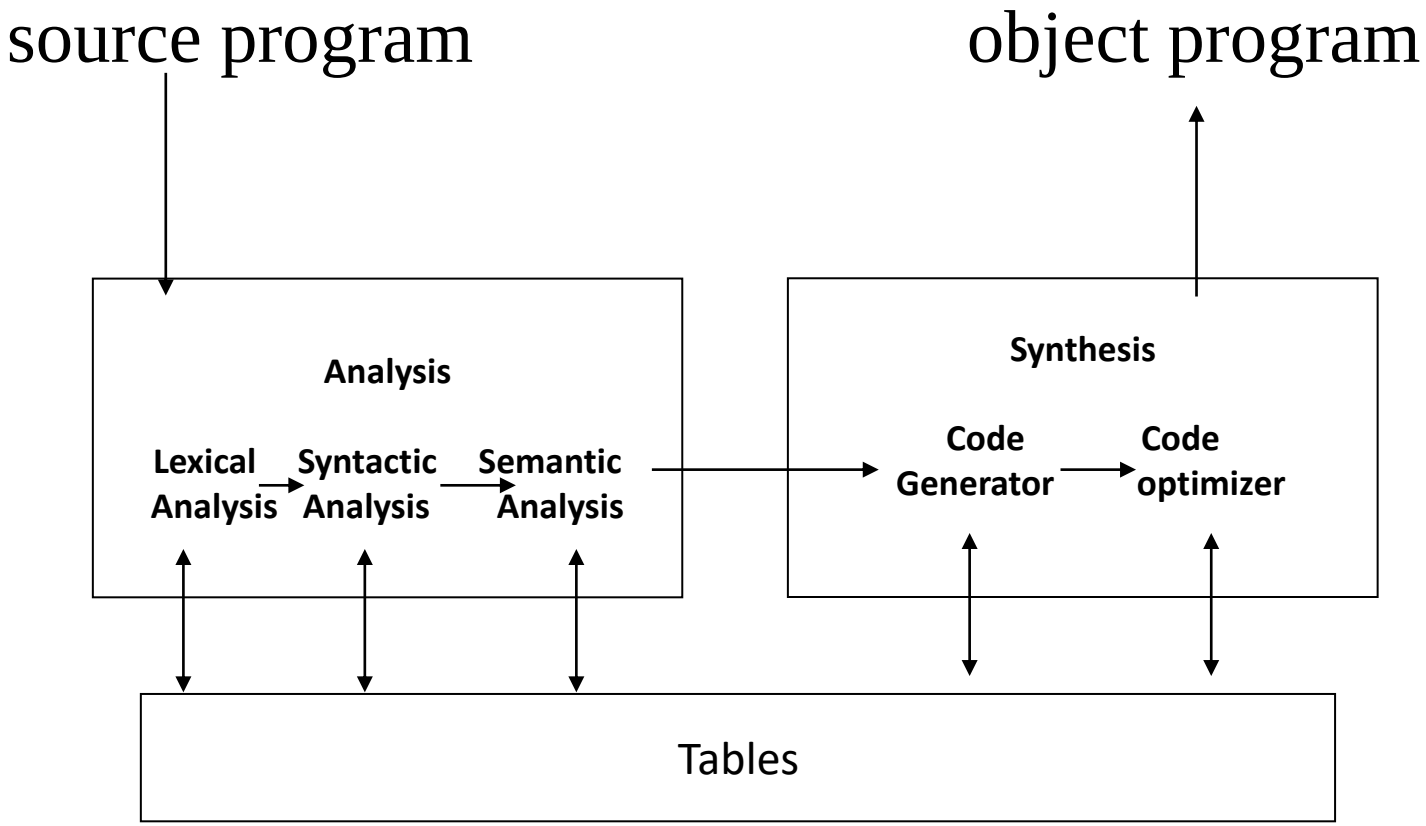
Compiler

- **Analysis** of source program: 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.
- **Synthesis** of its corresponding program: 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**.

Compiler

- Front End – Language Dependent – Depends on the source language and Target Independent
- Back End – Target Dependent – Depends on the target language but Source independent

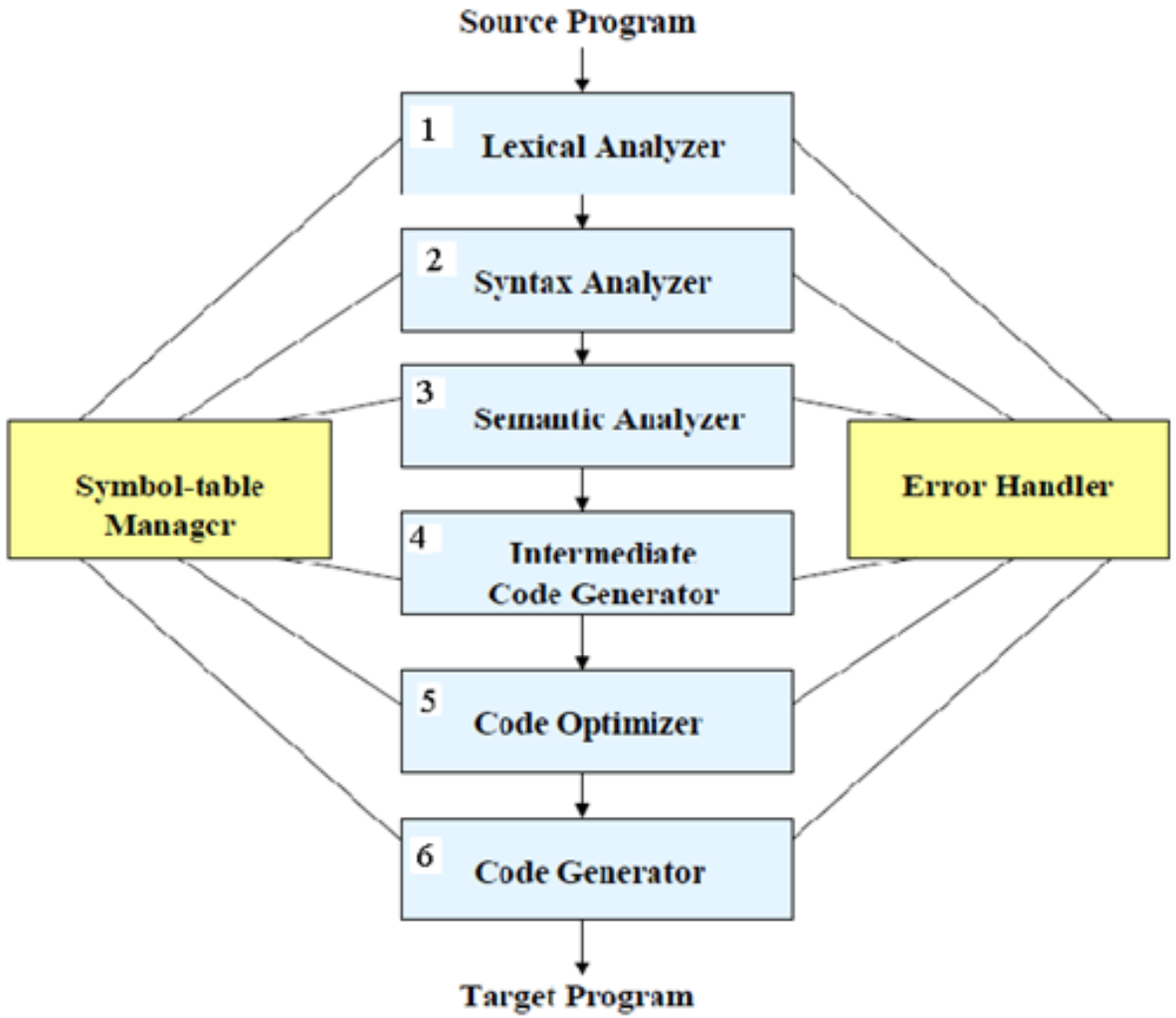
Flow of Compiler



Compiler Passes

- How many passes should the compiler go through?
- One for analysis and one for synthesis?
- One for each division of the analysis and synthesis?
- The work done by a compiler is grouped into phases

Phases of the compiler



Lexical Analysis (scanner): The first phase of a compiler

- Lexical analyzer reads the stream of characters from the source program and combines the characters into meaningful sequences called ***lexeme***
- For every lexeme, the lexer produces a token of the form which is passed to the next phase of the compiler

(token-name, attribute-value)

C identifiers.

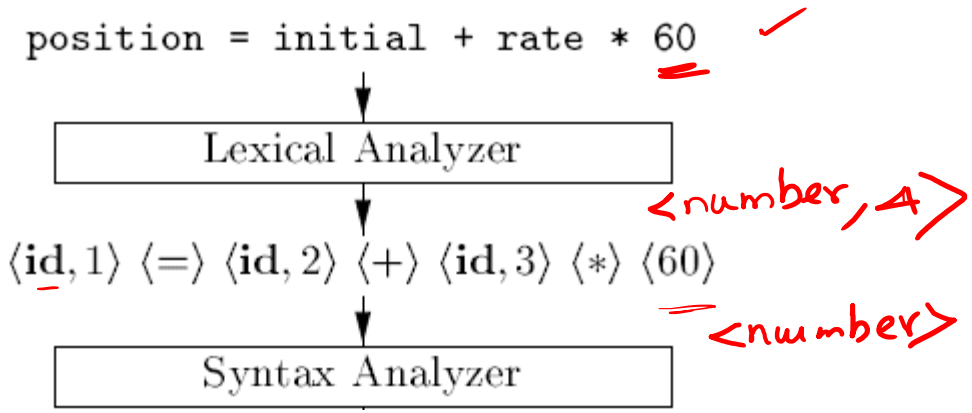
area

area_1

1area

Lexical Analysis (scanner): The first phase of a compiler

- Token-name: an abstract symbol is used during syntax analysis, an attribute-value: points to an entry in the symbol table for this token.
- Blanks will be discarded by the lexical analyser



SYMBOL TABLE

1	position	···
2	initial	···
3	rate	···
4		

Example: position =initial + rate * 60

1.”position” is a lexeme 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. = is a lexeme that is mapped into the token (=). Since this token needs no attribute-value, we have omitted the second component. For notational convenience, the lexeme itself is used as the name of the abstract symbol.

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 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 (60)

Lexical Analysis

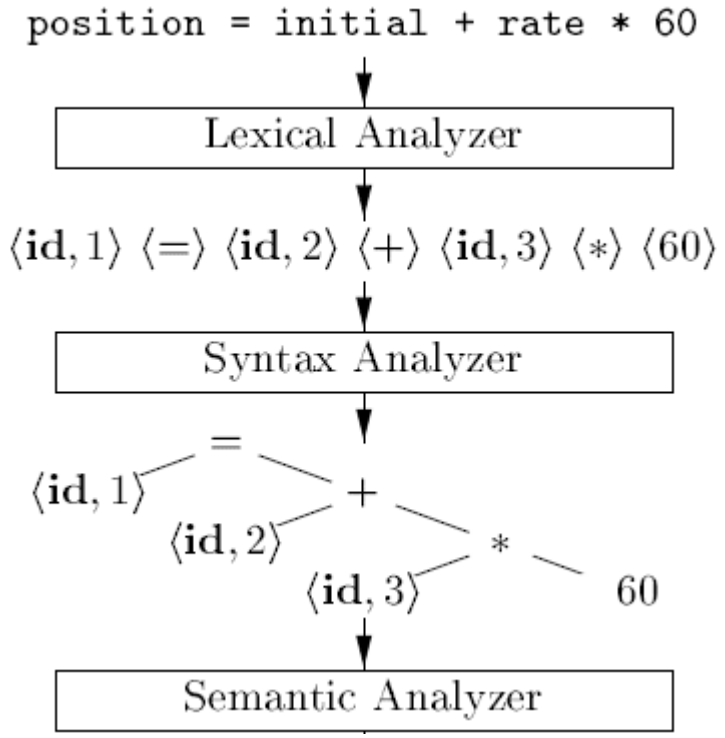
- Interface of the compiler to the outside world
- Scans input program, identifies valid words of the language in it
- Removes extra white spaces, comments etc
- Expand user defined macros
- Reports presence of foreign words
- May perform case conversions
- Generates tokens
- Generally implemented as finite automata

Syntax Analysis (parser) : The second phase of the compiler

- The parser uses the tokens produced by the lexer to create a tree-like intermediate representation that verifies the grammatical structure of the sequence of tokens
- Works hand-in-hand with lexical analyzer
- Identifies sequence of grammar rules to derive the input program from the start symbol
- A parse tree is constructed
- Error messages are flashed for syntactically incorrect programs

Syntax Analysis (parser) : The second phase of the compiler

- 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



Syntax phase

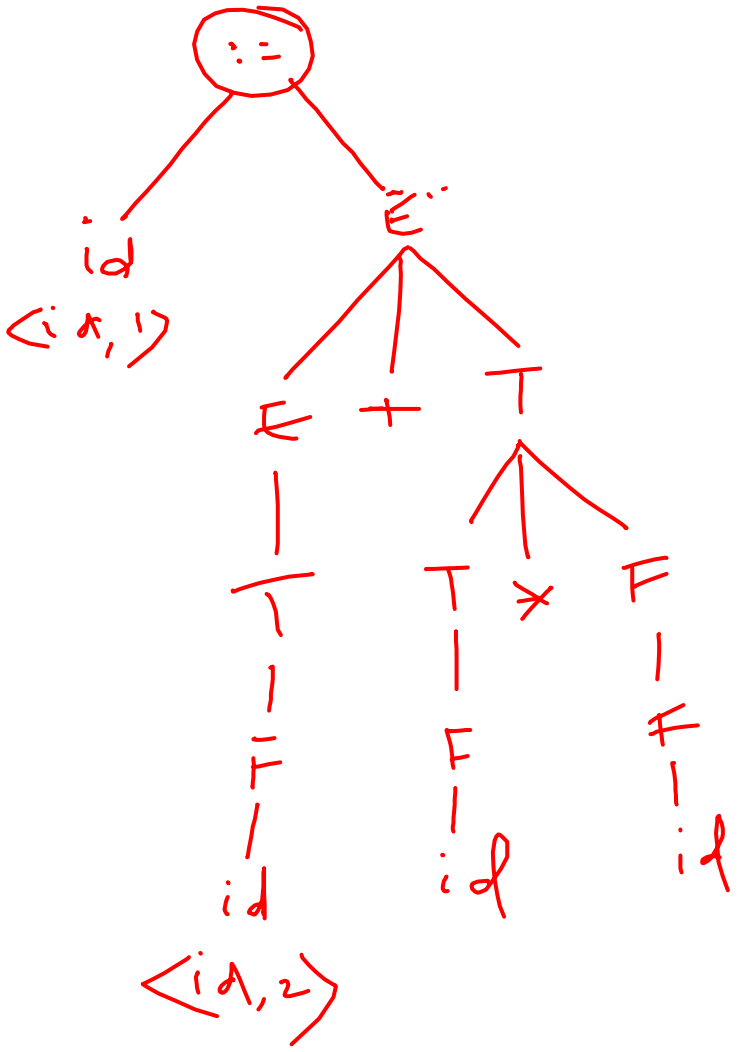
- Grammar for assignment expression

  S → id = E

  E → E + T | T

  T → T * F | F

  F → (E) | id

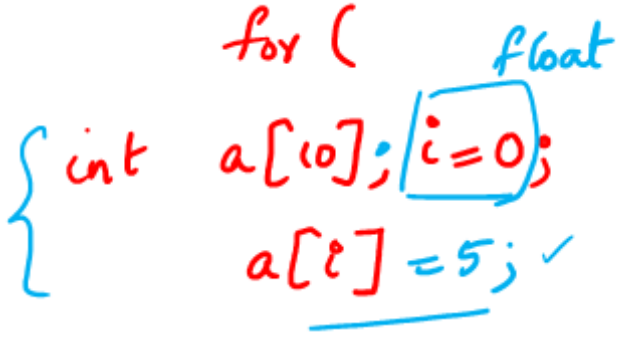


Semantic Analysis: Third phase of the compiler

- The semantic analyzer uses the output of the parser – syntax tree and the information in the symbol table to check for semantic consistency in the source program
- Gathers type information and saves it in either the syntax tree or the symbol table, for subsequent use during intermediate-code generation.

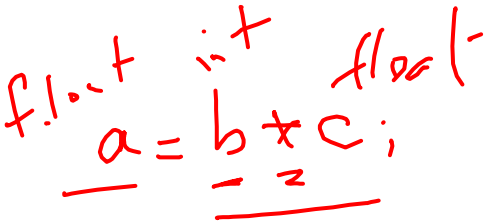
Semantic Analysis: Third phase of the compiler

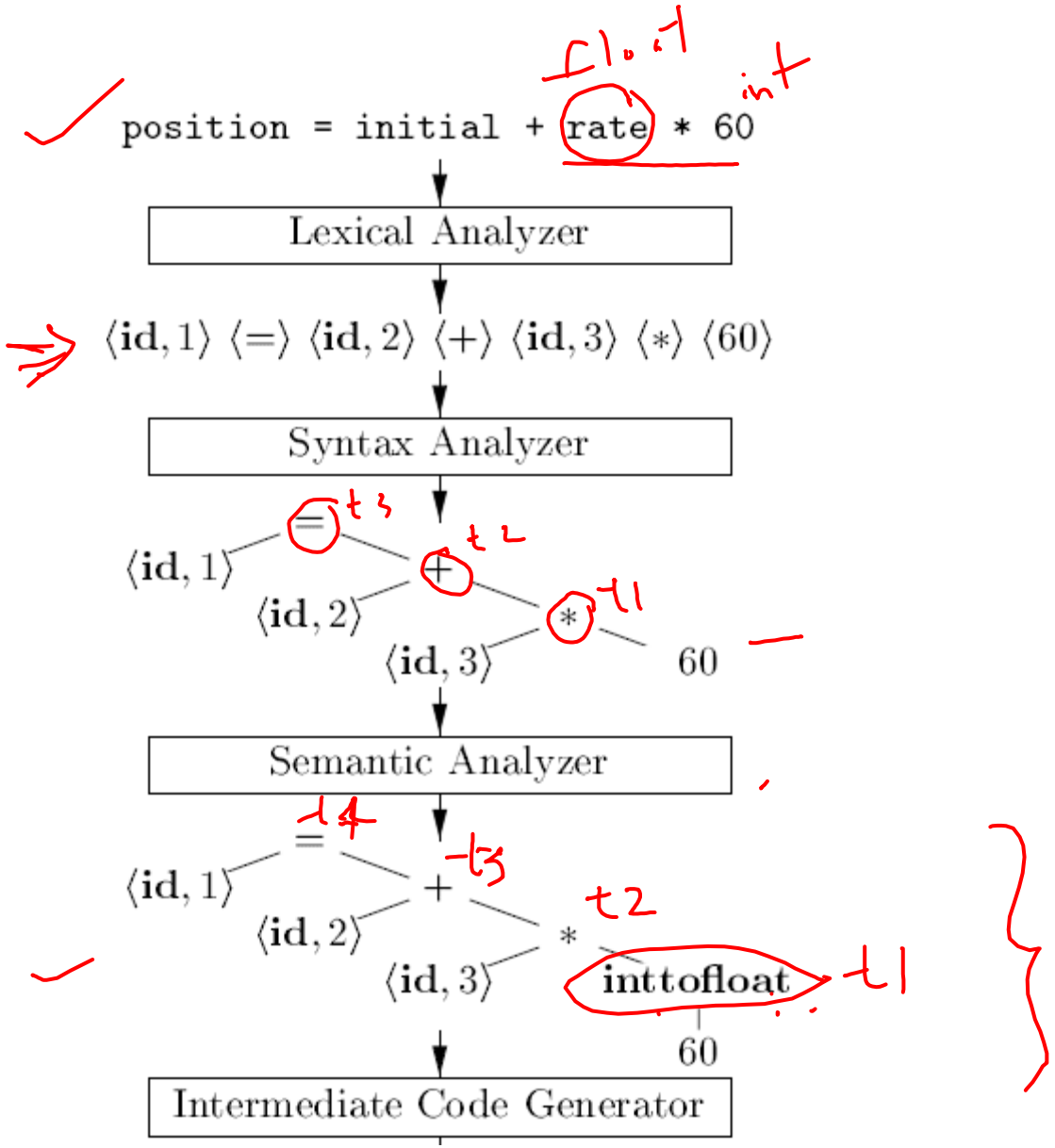
- Type checking, where the compiler checks that each operator has matching operands.
  - Array index need to be an integer; the compiler must identify an error if a floating-point number is used to as an array index
- Scope rules of the language are applied to determine types – static scope or dynamic scope



Semantic Analysis: Third phase of the compiler

- Coercions – a way of type conversion
- For example, a binary arithmetic operator may be applied to either a pair of integers or to a pair of floating-point numbers. If the operator is applied to a floating-point number and an integer, the compiler may convert or coerce the integer into a floating-point number.



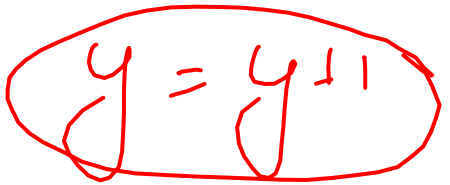

position = initial + rate * 60
Lexical Analyzer
⟨id, 1⟩ ⟨=⟩ ⟨id, 2⟩ ⟨+⟩ ⟨id, 3⟩ ⟨*⟩ ⟨60⟩
Syntax Analyzer
=
⟨id, 1⟩
+
⟨id, 2⟩
*
⟨id, 3⟩
60
Semantic Analyzer
=
⟨id, 1⟩
+
⟨id, 2⟩
*
⟨id, 3⟩
inttofloat
60
Intermediate Code Generator

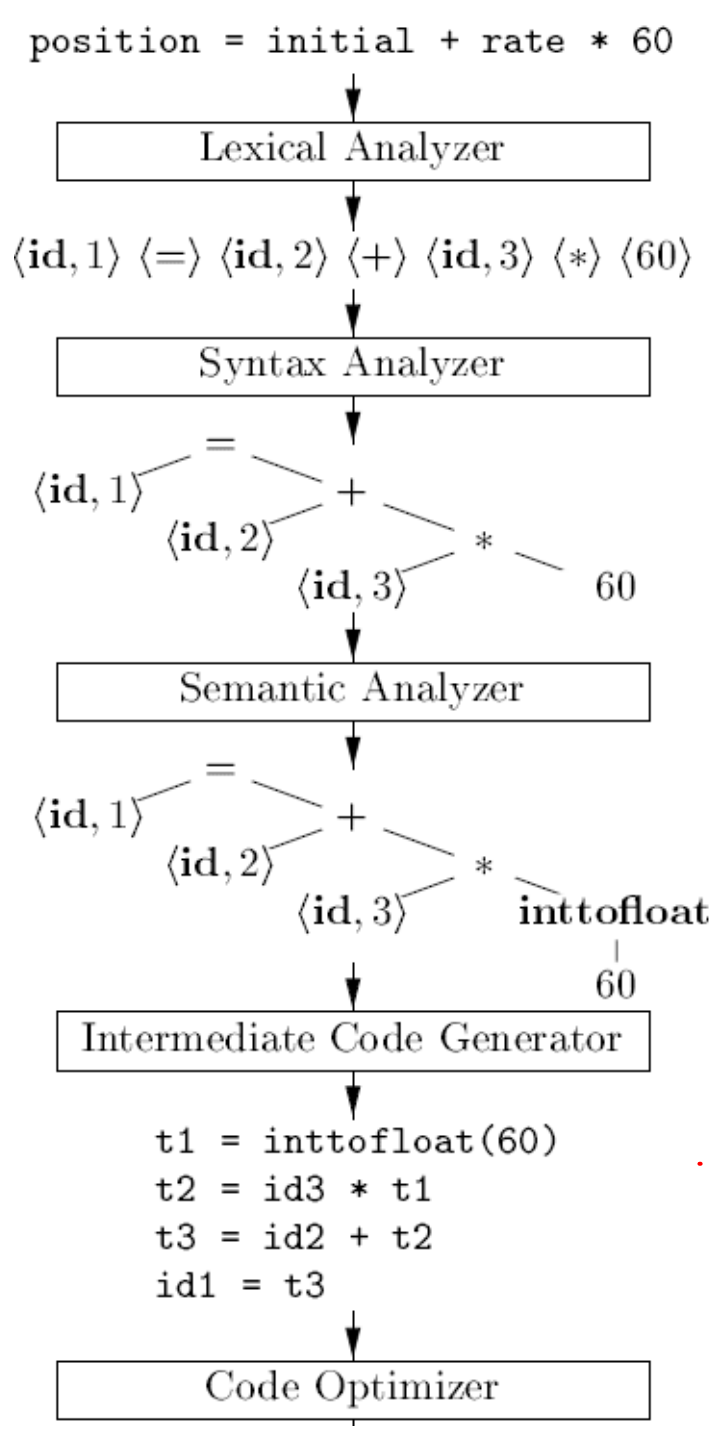
Intermediate Code Generation: Fourth phase of the compiler

- Optional towards target code generation
- Compilers generate an explicit low-level or machine-like intermediate representation (a program for an abstract machine).This intermediate representation:
  - should be easy to produce
  - should be easy to translate into the target machine
  - Powerful enough to express the programming language constructs
- Helps to retarget the code from one processor to another

Intermediate code Generation : Three address code

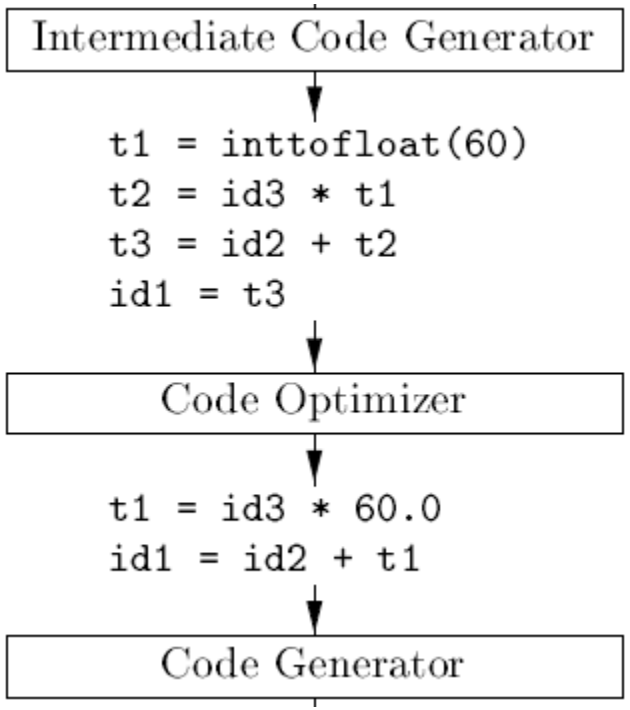
- A convention for Intermediate code generation is three address code
- Three operands at the most and 2 operators
- Example:
  - x = y op z
  - x = op y




position = initial + rate * 60
Lexical Analyzer
⟨id, 1⟩ ⟨=⟩ ⟨id, 2⟩ ⟨+⟩ ⟨id, 3⟩ ⟨∗⟩ ⟨60⟩
Syntax Analyzer
=
⟨id, 1⟩
+
⟨id, 2⟩
*
⟨id, 3⟩
60
Semantic Analyzer
=
⟨id, 1⟩
+
⟨id, 2⟩
*
⟨id, 3⟩
inttofloat
60
Intermediate Code Generator
t1 = inttofloat(60)
t2 = id3 * t1
t3 = id2 + t2
id1 = t3
Code Optimizer

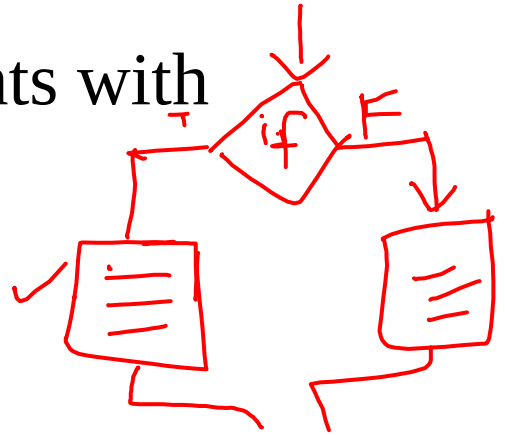
Code Optimization: - Fifth phase of the compiler

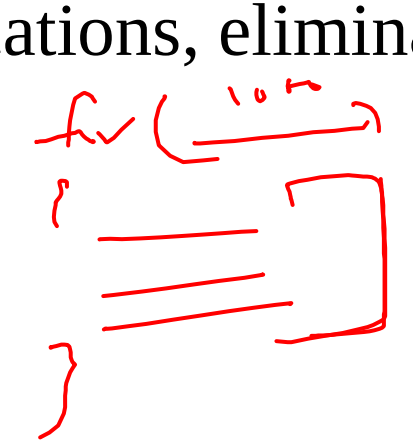
- attempts to improve the intermediate code for better target code
  - faster, shorter code, or target code that consumes less power.
- simple optimizations that significantly improve the running time of the target program without slowing down compilation

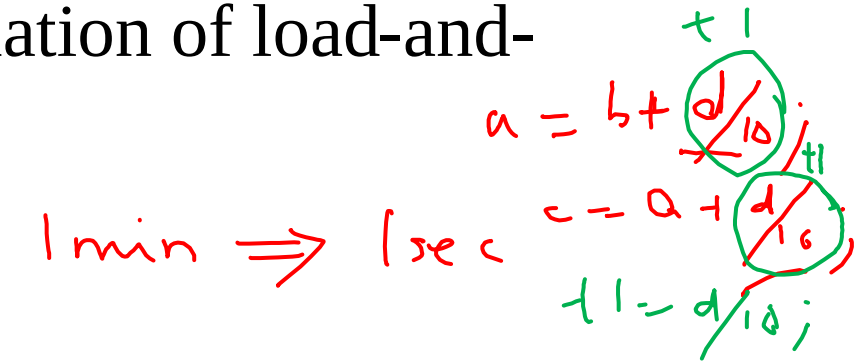


Code Optimization: - Fifth phase of the compiler

- Automated steps of compiler generate lots of redundant code that can possibly eliminated
- Code is divided into *basic blocks* – a sequence of statements with single entry and exit
- *Local optimizations* restrict within a single basic block
- *Global optimizations* spans across basic blocks
- Optimize loops, algebraic simplifications, elimination of load-and-store are common optimizations

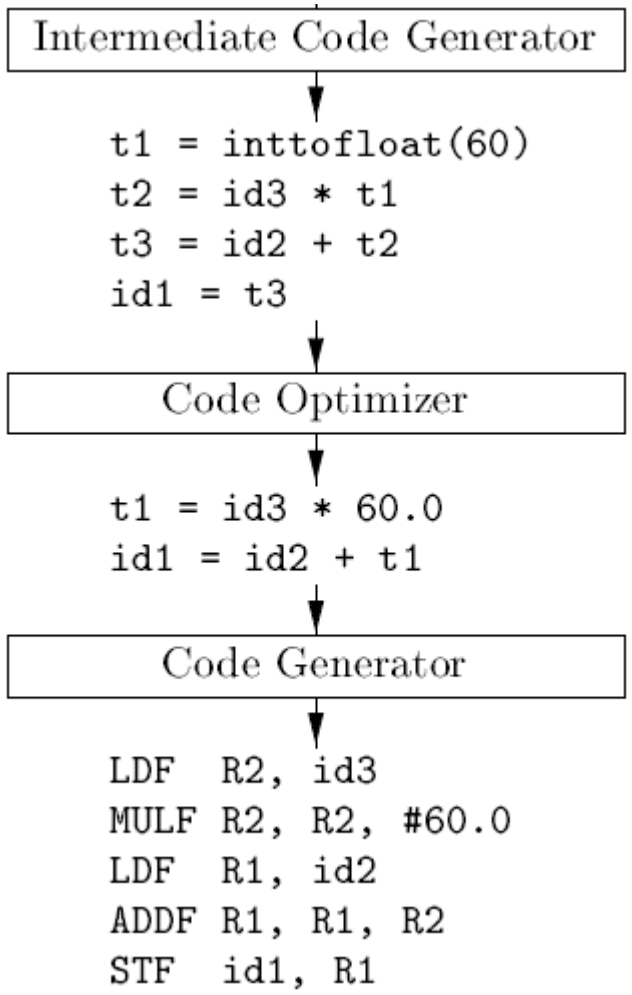






Code Generation: Sixth phase of the compiler

- If the target language is machine code, then registers or memory locations are selected for each of the variables used by the program.
- Then, the intermediate instructions are translated into sequences of machine instructions to complete an operation



Code Generation: Sixth phase of the compiler

- Important consideration of code generation is the assignment of registers to hold variables.
- Choice of instructions involving registers, memory or a mix of the two

Symbol-Table Management: - Interaction with all the compiler's phases

- The symbol table is a data structure containing a record for each variable name (all symbols defined in the source program), with fields for the attributes of the name.
- The data structure is designed to help the compiler to identify and fetch the record for each name quickly
- To store or retrieve data from that record quickly
- Not part of the final code, but used as reference by all phases
- Generally created by lexical and syntax analyzer

Symbol-Table Management: - Interaction with all the compiler’s phases

- attributes may provide information about the storage allocated for a name, its type, its scope, size, relative offset of variables
- Function or Procedure names, the number and types of its arguments, the method of passing each argument and the return type

Error Handling and Recovery

- An important criteria for selecting the quality of the compiler
- For semantic errors, compiler can proceed
- For syntax errors, parser enters into erroneous state
- Needs to undo some processing already carried out by parser
- A few tokens may need to be discarded to reach a descent state
- Recovery is essential to provide a bunch of errors to the users

Compiler Phases vs Passes

- Several phases can be implemented as a single pass consist of reading an input file and writing an output file.

Compiler Phases vs Passes

- A typical multi-pass compiler looks like:
  - First pass: preprocessing, macro expansion
  - Second pass: syntax-directed translation, IR code generation
  - Third pass: optimization
  - Last pass: target machine code generation

Cousins of Compilers

- Preprocessors
- Assemblers
  - Compiler may produce assembly code instead of generating relocatable machine code directly.

Cousins of the Compiler

- Loaders and Linkers
  - Loader copies code and data into memory, allocates storage, setting protection bits, mapping virtual addresses, .. Etc
  - Linker handles relocation and resolves symbol references.
- Debugger