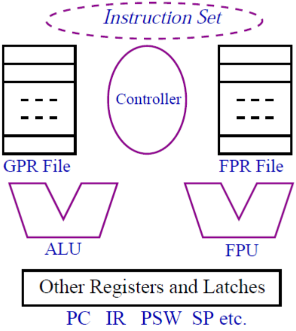
Introduction

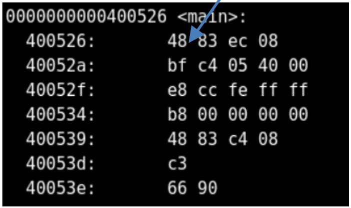
- Programs are the instructions written in high-level languages.
    - Source code -- User convenience
- Computer executes the programs written in machine language
    - Machine code --- machine convenience

Computer Architecture

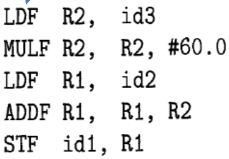


Op code

Mnemonics



```
0000000000400526 <main>:
  400526:       48 83 ec 08
  40052a:       bf c4 05 40 00
  40052f:       e8 cc fe ff ff
  400534:       b8 00 00 00 00
  400539:       48 83 c4 08
  40053d:       c3
  40053e:       66 90
```



```
LDF  R2,  id3
MULF R2,  R2, #60.0
LDF  R1,  id2
ADDF R1,  R1, R2
STF  id1, R1
```

Machine code
Machine dependent

Assembly code

Introduction

- Programs are the instructions written in high-level languages.
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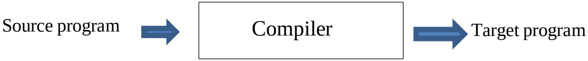
- Programming in machine language requires memorization of the binary codes — difficult for program-writers
- Hence, the requirement of **Compilers**

Introduction

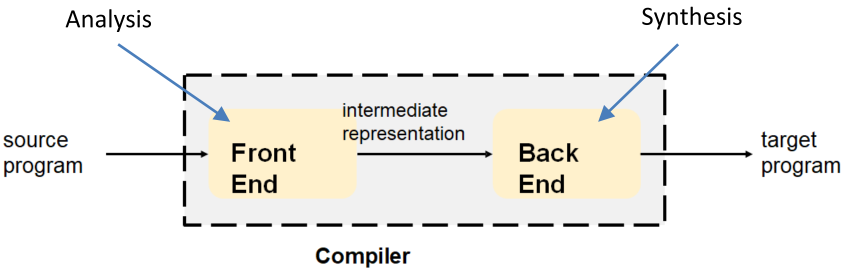
- A Compiler is a **software**
- Task of a compiler
    - Read a program in one language (**source**) and
    - Translate it into an equivalent program in machine language (**target**)



- Report any errors in the source program that it detects during the translation process.

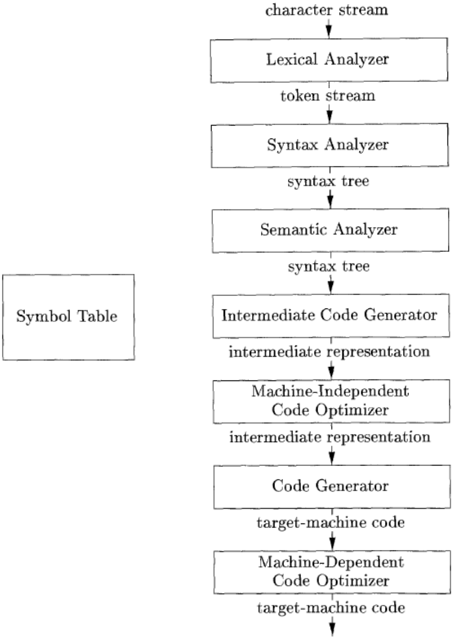
- We use compilers for generating **target machine** language program from the input high-level language program
- Target program is used by user to generate output from input

Compiler structure



- Analysis and Synthesis
- Analysis - Breaks up the source program and imposes grammatical rules on them (**front-end**)
    - Generates IR
    - Detects errors
    - Constructs **Symbol table**
- Synthesis - Constructs the target program from intermediate representation & the symbol table (**back-end**)

The Phases of a Compiler



character stream

Lexical Analyzer

token stream

Syntax Analyzer

syntax tree

Semantic Analyzer

syntax tree

Intermediate Code Generator

intermediate representation

Machine-Independent Code Optimizer

intermediate representation

Code Generator

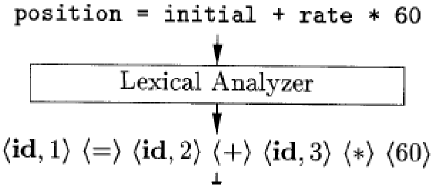
target-machine code

Machine-Dependent Code Optimizer

target-machine code

Symbol Table

Lexical Analysis



`position = initial + rate * 60`

Lexical Analyzer

$\langle \mathbf{id}, 1\rangle\ \langle = \rangle\ \langle \mathbf{id}, 2\rangle\ \langle + \rangle\ \langle \mathbf{id}, 3\rangle\ \langle * \rangle\ \langle 60 \rangle$

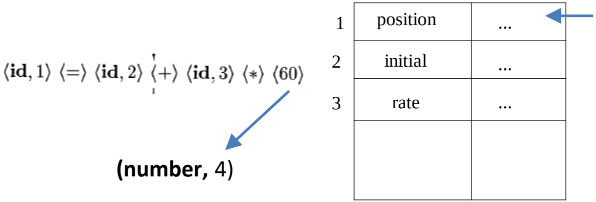
- Reads the stream of characters making up the source program and groups the characters into meaningful sequences called **lexemes**
- For each lexeme, the LA produces the **token**, (a) passed to the syntax analyzer, (b) inserted in the **symbol table**

  <token-name, attribute-value>

- **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
- **Blanks separating the lexemes** would be **discarded** by the lexical analyzer.

Lexical Analysis

id is an abstract symbol standing for identifier and 1 points to the symbol table entry for **position**.



$\langle \mathbf{id}, 1\rangle \; \langle = \rangle \; \langle \mathbf{id}, 2\rangle \; \langle + \rangle \; \langle \mathbf{id}, 3\rangle \; \langle * \rangle \; \langle 60 \rangle$

(number, 4)

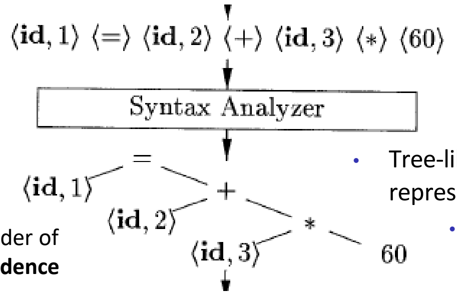
1	position	...
2	initial	...
3	rate	...

information about the **id**, such as its name and type

- *position* is mapped to a token <id, 1> where **id** stands for identifier and 1 points to symbol table entry for position
- *, **+** map into the token <+>, <*>, respectively

Syntax Analysis – Parsing

```
position = initial + rate * 60
```



⟨**id**, 1⟩ ⟨=⟩ ⟨**id**, 2⟩ ⟨+⟩ ⟨**id**, 3⟩ ⟨∗⟩ ⟨60⟩

Syntax Analyzer

Tree depicts the order of operations – **precedence**

- Tree-like intermediate representation
  - Syntax tree

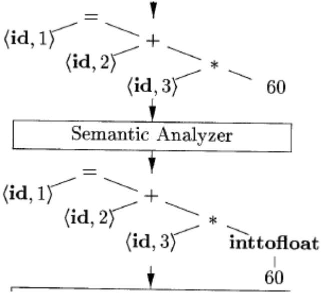
- The parser uses the **tokens** produced by the lexical analyzer to create a tree-like intermediate representation
  - Depicts the **grammatical structure of the token stream**.

- The **internal nodes** represent **operation** and the **leaf nodes** represent **arguments** of the operation

- **Context-free grammars** are used to represent grammatical structure (say, precedence of operations)

Semantic Analysis

- Uses **syntax tree** and the **symbol table** for checking semantic consistency
- **Type checking** is one of the major part — the analyzer checks whether each operator has matching operands



Binary arithmetic operator may be applied to
(i) either a pair of integers or (ii) to a pair of floating-point numbers.
If the operator is applied to a floating-point number and an integer, the compiler may convert the integer into a floating-point number.

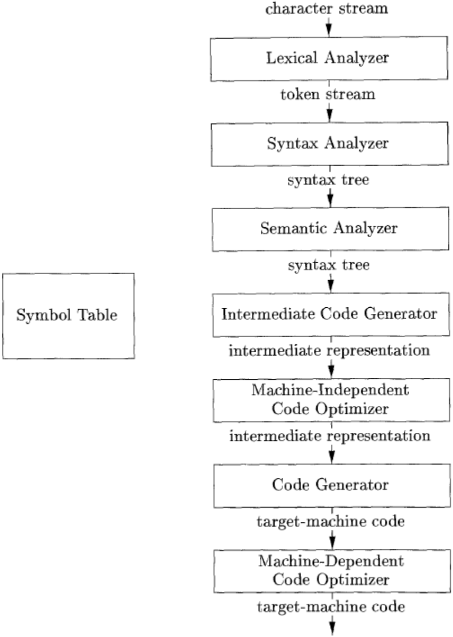
position, *initial*, *rate* are floating point numbers

Lexeme **60** is an integer — it is **type casted** to a floating point number

Type-casting are performed in this phase

The information is stored into syntax tree or in symbol table

The Phases of a Compiler



character stream

Lexical Analyzer

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syntax tree

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Intermediate Code Generator

intermediate representation

Machine-Independent Code Optimizer

intermediate representation

Code Generator

target-machine code

Machine-Dependent Code Optimizer

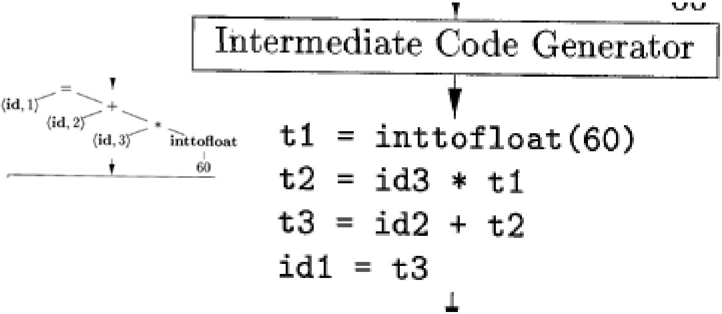
target-machine code

Symbol Table

Intermediate Code Generation

- In the process of translating a source program into target code,
  - compiler constructs multiple **intermediate representations**
    - various forms of Intermediate code (syntax tree etc)
  - Explicit low-level or machine-like intermediate representation, which we can think of as a program for an abstract machine
- (a) IR should be easy to produce and (b) it should be easy to translate into the target machine.
- Three address code
  - **Three operands** per instruction
  - **At most one operator** at the right hand side

Intermediate Code Generation



```
t1 = inttofloat(60)
t2 = id3 * t1
t3 = id2 + t2
id1 = t3
```

Notable points:

(a) Each three-address assignment instruction has **at most one operator** on the right side.

Thus, these instructions fix the order in which operations are to be done; **the multiplication precedes the addition**.

(b) The compiler must generate a **temporary name** to hold the value computed by a three-address instruction.

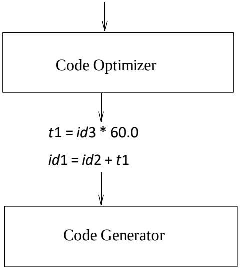
(c) some "three-address instructions" like the first and last in the sequence, above, have **fewer than three operands**

Code Optimization

- Machine independent code-optimization phase attempts to improve the intermediate code so that **better code** is generated in terms of **time and space**
- A significant amount of time is spent on this phase
- Mostly simple optimizations are tried which improves the code without slowing down compilation

Code Optimization

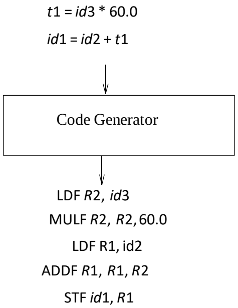
```
t1 = inttofloat(60)
t2 = id3 * t1
t3 = id2 + t2
id1 = t3
```



```
t1 = id3 * 60.0
id1 = id2 + t1
```

- ► Conversion of 60 from integer to float to eliminate *inttofloat* operation
- ► A shorter sequence is sorted out

Code Generation



$t1 = id3 * 60.0$

$id1 = id2 + t1$

Code Generator

LDF $R2,\ id3$

MULF $R2,\ R2, 60.0$

LDF R1, id2

ADDF $R1,\ R1,\ R2$

STF $id1,\ R1$

- Input : intermediate representation, Output : target code
- Registers and memory locations are selected for each variable used by the program
- Example : above generated code uses only registers $R1$and $R2$
- First operand is the destination