1.1 What is a Compiler?

I. Translator

Definition:

\[
\text{program in language } X \quad \rightarrow \quad \text{translator for language } X \quad \rightarrow \quad \text{program in language } Y
\]
### Examples:

<table>
<thead>
<tr>
<th>Source Language</th>
<th>Object Language</th>
<th>Name</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
<td>preproc</td>
<td>ratfor → f77 m4, cpp</td>
</tr>
<tr>
<td>Assem.</td>
<td>Mach.</td>
<td>assemb</td>
<td>as</td>
</tr>
<tr>
<td>High</td>
<td>Mach.</td>
<td>compil</td>
<td>g++, javac</td>
</tr>
<tr>
<td>Any Level</td>
<td>executes</td>
<td>interp</td>
<td>BASIC c shell apl, lisp java</td>
</tr>
</tbody>
</table>
• Preprocessor

\[
\text{for } i=1 \text{ to } n \text{ do } \\
(\text{stmts}) \\
\text{end for}
\]

\[
\downarrow
\]

\[i = 1\]

\[
\text{while } (i \leq n) \text{ do } \\
(\text{stmts}) \\
i = i + 1 \\
\text{end while}
\]
skeletal source program
↓

preprocessor
↓

source program
↓

compiler
↓

target (object) assembly program
↓

assembler
↓

relocatable machine code
↓

loader/link-editor
↓

absolute machine code
III. Compiler

program in high level language X → compiler for X → program in machine language Y
1.2 STRUCTURE OF A COMPILER

General Overview

Source Code

Lexical Analysis

tokens

Syntax Analysis

parse trees

Symbol Table Management

Intermediate Code Generation

intermediate code

Error Handling

Code Optimization

intermediate code

Code Generation

Object Program
1.3 PHASES OF COMPILATION

1.3.1 Lexical Analysis (Scanner)

a. Purpose: Read the same program character by character grouping them into atomic units called “tokens.”

b. Tokens:

- depend on language and compiler writer
- Examples:
  - reserved words: if, for
  - operators: +, −, <, =
  - constants: 0, 4.89
  - punctuation: (, }, [ 
  - identifiers: sb, ch

- treated as a pair: token.type and token.value
c. Example

if (x <= 0) x = y + z

when put through lexical analyzer produces:

<table>
<thead>
<tr>
<th>token</th>
<th>type</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>if</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>id</td>
<td>23</td>
<td>“x”</td>
</tr>
<tr>
<td>&lt;=</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>int constant</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>)</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>id</td>
<td>23</td>
<td>“x”</td>
</tr>
<tr>
<td>= assignment</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>id</td>
<td>23</td>
<td>“y”</td>
</tr>
<tr>
<td>+</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>id</td>
<td>23</td>
<td>“z”</td>
</tr>
</tbody>
</table>
d. How does one build a lexical analyzer?

- from scratch
- lex

e. Preview of Lex

- idea: tokens described by regular expressions
- basic syntax: regular expression, action
- basic semantics: if match regular expression, then do action.

- Example:
  ```
  %%
  "if" return(25);
  "(" return(28);
  [0-9]+ return(22);
  ```

f. Remarks
Besides returning token types and values, the lexical analyzer might
a) print error messages
b) insert identifiers in the symbol table

1.3.2 Syntax Analysis (Parsing)
a. Purpose:
b. Syntax:
c. Parse Tree

\[
\text{if } (x \leq 0) \ x = y + z
\]

\[
\begin{align*}
\text{statement} \\
\text{if-statement} \\
\text{if} ( \ ) \\
\text{condition} \\
\text{relation} \\
\text{expression} \\
\text{id} \\
\text{rel} \\
\leq \\
\text{expression} \\
\text{constant} \\
\text{expression} \\
\text{lhs} \\
\text{id} \\
\text{expr} \\
\text{expr} \\
\text{expr} \\
= \\
\text{rhs} \\
\text{id} \\
\text{id}
\end{align*}
\]

d. How does one build a parser?

- from scratch
- using a parser generator such as yacc
1.3.3 Intermediate Code Generator

a. Purpose: Traverse the parse tree, producing simple intermediate code.

b. Three-Address Code:

Instructions:

1. id := id op id
2. goto label
3. if condition goto label
Example:

\[
\text{if } (x <= 0) \ x = x + z
\]

\[
\downarrow
\]

\[
\text{if } (x <= 0) \ \text{goto L1}
\]

\[
\text{goto L2}
\]

L1: \ x := y + z

L2:

1.3.4 Intermediate Code Generation

a. Purpose: Transform the intermediate code into “better” code.
b. Examples

1) Rearrangement of Code

\[
\begin{align*}
\text{if } (x \leq 0) & \text{ goto L1} & \text{if } (x > 0) & \text{ goto L2} \\
goto \text{ L2} & & \rightarrow & x = y + z \\
\text{L1: } x = y + z & & \text{L2: } & \\
\text{L2: } & & & \\
\end{align*}
\]

2) Redundancy Elimination

\[
\begin{align*}
a = w + x + y & & T1 = x + y & & \rightarrow & a = w + T1 \\
b = x + y + z & & b = T1 + z & & & \\
\end{align*}
\]
3) Strength Reduction

\[ x^2 \quad \rightarrow \quad x \times x \]

expensive \quad \rightarrow \quad cheap
operator \quad \rightarrow \quad operator

4) Frequency Reduction

\[
\text{for } (i=1; \ i<n; \ i=i+1) \ \{ \ T1 = \sqrt{26} \\
\quad x = \sqrt{26} \quad \rightarrow \text{for } (i=1; \ i<n; \ i=i+1) \\
\quad \} \\
\quad \} \\
\quad x = T1
\]

c. Remarks:

1) Main criteria for optimization is speed.
1.3.5 Code Generation

a. Purpose: Transform intermediate code to machine code (assembler)

b. Example: \( a = b + c \)

\[
\begin{align*}
\text{mov} & \quad \text{b, R1} \\
\text{add} & \quad \text{c, R1} \\
\text{mov} & \quad \text{R1, a}
\end{align*}
\]

c. Remarks
1.4 Symbol Table

a. Purpose: record information about various objects in the source program

b. Examples

- procedure - no. and type of arguments
- simple variable - type
- array - type, size

c. Use - information is required during

- parsing
- code generation
1.5 Error Handler

a. Errors - all errors should be

- detected
- detected correctly
- detected as soon as possible
- reported at the appropriate place and in a helpful manner

b. Purpose

- report errors
- “error recovery” - proceed with processing
c. **Note:** Errors can occur in each phase

- misspelled token
- wrong syntax
- improper procedure call
- statements that cannot be reached