Introduction to Compiler Construction

ASU Textbook Chapter 1

Tsan-sheng Hsu

tshsu@iis.sinica.edu.tw

`http://www.iis.sinica.edu.tw/~tshsu`

What is a compiler?

- **Definitions:**
  - a **recognizer**;
  - a **translator**.

  - **Source and target must be equivalent!**
- **Compiler writing spans:**
  - **programming languages;**
  - **machine architecture;**
  - **language theory;**
  - **algorithms and data structures;**
  - **software engineering.**
- **History:**
  - **1950: the first FORTRAN compiler took 18 man-years;**
  - **now: using software tools, can be done in a few months as a student's project.**

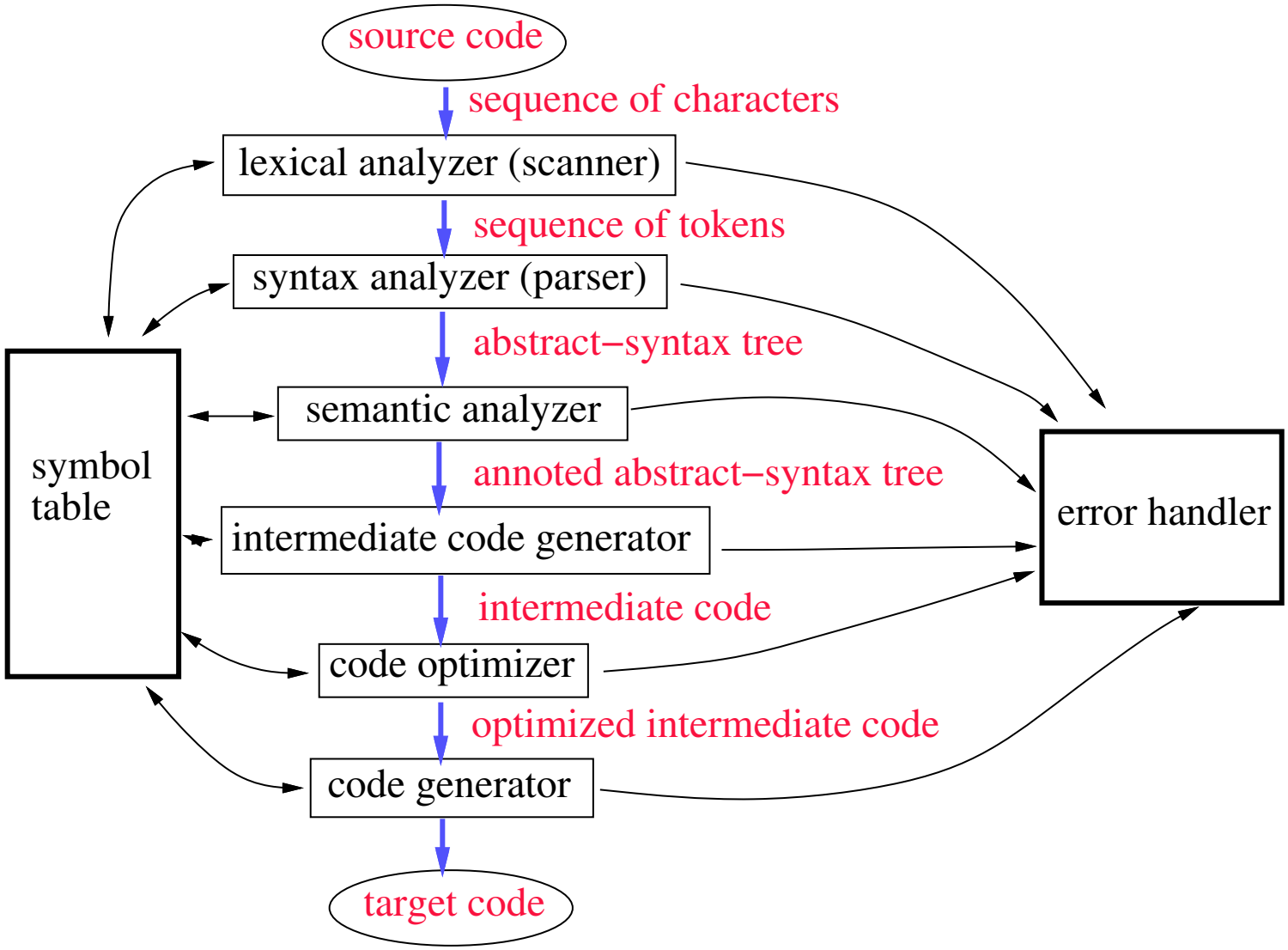
Applications

- **Computer language compilers.**
- **Translator: from one format to another.**
  - **query interpreter**
  - **text formatter**
  - **silicon compiler**
  - **infix notation $\rightarrow$ postfix notation:**

$$\boxed{3+5-6*6} \Rightarrow \boxed{3 \quad 5 \quad + \quad 6 \quad 6 \quad * \quad -}$$

  - **pretty printers**
  - $\cdots$
- **Computational theory:**
  - **a set of grammar rules $\equiv$ the definition of a particular machine.**
    - ▷ ***also equivalent to a set of languages recognized by this machine.***
  - **a type of machines: a family of machines with a given set of operations, or capabilities;**
  - **power of a type of machines**
    $\equiv$ the set of languages that can be recognized by this type of machines.

Flow chart of a typical compiler



Scanner

- **Actions:**
  - **Reads characters from the source program;**
  - **Groups characters into lexemes, i.e., sequences of characters that "go together", following a given pattern;**
  - **Each lexeme corresponds to a token.**
    - ▷ *the scanner returns the next token, plus maybe some additional information, to the parser;*
  - **The scanner may also discover lexical errors, i.e., erroneous characters.**
- **The definitions of what a lexeme, token or bad character is depend on the definition of the source language.**

Scanner example for C

- **Lexeme: C sentence**

L1: x = y2 + 12;

(Lexeme)	**L1**	**:**	**x**	**=**	**y2**	**+**	**12**	**;**
(Token)	**ID**	**COLON**	**ID**	**ASSIGN**	**ID**	**PLUS**	**INT**	**SEMI-COL**

- **Arbitrary number of blanks between lexemes.**
- **Erroneous sequence of characters, that are not parts of comments, for the C language:**
  - **control characters**
  - **@**
  - **2abc**

Parser

- **Actions:**
  - Group tokens into **grammatical phrases**, to discover the underlying structure of the source
  - Find **syntax errors**, e.g., the following C source line:

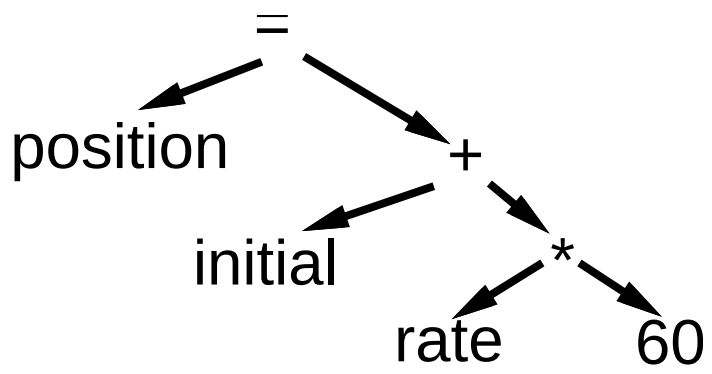
    (Lexeme) index = 12 * ;

    (Token) ID ASSIGN INT TIMES SEMI-COL

    Every token is legal, but the sequence is erroneous!
- May find some **static semantic errors**, e.g., use of undeclared variables or multiple declared variables.
- May generate code, or build some intermediate representation of the source program, such as an abstract-syntax tree.

Parser example for C

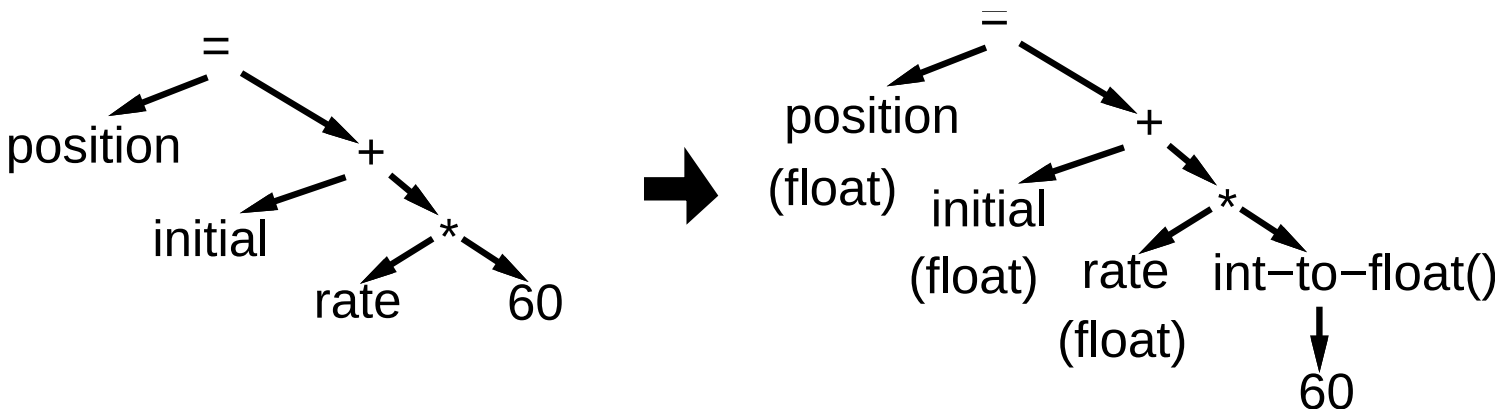
- **Source code:** $position = initial + rate * 60;$
- **Abstract-syntax tree:**



- **interior nodes of the tree are OPERATORS;**
- **a node's children are its OPERANDS;**
- **each subtree forms a logical unit .**
- **the subtree with $*$ at its root shows that $*$ has higher precedence than $+$, the operation "$rate * 60$" must be performed as a unit, not "$initial + rate$".**

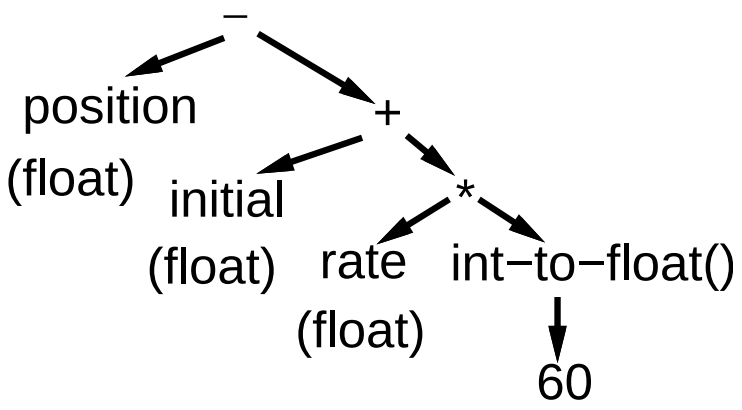
Semantic analyzer

- **Actions:**
  - **Check for more static semantic errors, e.g., type errors.**
  - **May annotate and/or change the abstract syntax tree.**



Intermediate code generator

- **Actions: translate from abstract-syntax trees to intermediate codes.**
- **One choice for intermediate code is 3-address code :**
  - **Each statement contains**
    - ▷ *at most 3 operands;*
    - ▷ *in addition to ":=", i.e., assignment, at most one operator.*
  - **An"easy" and "universal" format that can be translated into most assembly languages.**
- **Example:**



temp1 := int-to-float(60)

temp2 := rate * temp1

temp3 := initial + temp2

position := temp3

Optimizer

- Improve the efficiency of intermediate code.
- Goal may be to make code run faster, and/or to use least number of registers $\cdots$
- Example:

```
temp1 := int-to-float(60)
temp2 := rate * temp1
temp3 := initial + temp2
position := temp3
```

$\Rightarrow$

```
temp2 := rate * 60.0
position := initial + temp2
```

- Current trends:
  - to obtain smaller, but maybe slower, equivalent code for embedded systems;
  - to reduce power consumption.

Code generation

- **A compiler may generate**
  - **pure machine codes (machine dependent assembly language) directly, which is rare now;**
  - **virtual machine code.**
- **Example:**
  - **PASCAL $\rightarrow$ compiler $\rightarrow$ P-code $\rightarrow$ interpreter $\rightarrow$ execution**
  - **Speed is roughly 4 times slower than running directly generated machine codes.**
- **Advantages:**
  - **simplify the job of a compiler;**
  - **decrease the size of the generated code: 1/3 for P-code;**
  - **can be run easily on a variety of platforms**
    - ▷ *P-machine is an ideal general machine whose interpreter can be written easily;*
    - ▷ *divide and conquer;*
    - ▷ *recent example: JAVA and Byte-code.*

Code generation example

temp2 := rate * 60.0

position := initial + temp2

$\Longrightarrow$

LOADF	rate, R_1
MULF	#60.0, R_1
LOADF	initial, R_2
ADDF	R_2, R_1
STOREF	R_1, position

Practical considerations (1/2)

- **Preprocessing phase:**
  - **macro substitution:**
    - *#define MAXC 10*
  - **rational preprocessing: add new features for old languages.**
    - *BASIC*
    - $C \rightarrow C++$
  - **compiler directives:**
    - *#include <stdio.h>*
  - **non-standard language extensions.**
    - *adding parallel primitives*

Practical considerations (2/2)

- **Passes of compiling**
  - First pass reads the text file once.
  - May need to read the text one more time for any **forward addressed** objects, i.e., anything that is used before its declaration.
  - Example: C language

```
goto error_handling;
...
error_handling:
...
```

Reduce number of passes

- Each pass takes I/O time.
- **Back-patching**: leave a blank slot for missing information, and fill in the empty slot when the information becomes available.
- Example: C language
  when a label is used
  - if it is not defined before, save a **trace** into the to-be-processed table
    - ▷ *label_name corresponds to LABEL_TABLE[i]*
  - code generated: GOTO LABEL_TABLE[i]

  when a label is defined
  - check known labels for redefined labels
  - if it is not used before, save a trace into the to-be-processed table
  - if it is used before, then find its trace and fill the current address into the trace
- **Time and space trade-off** !