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

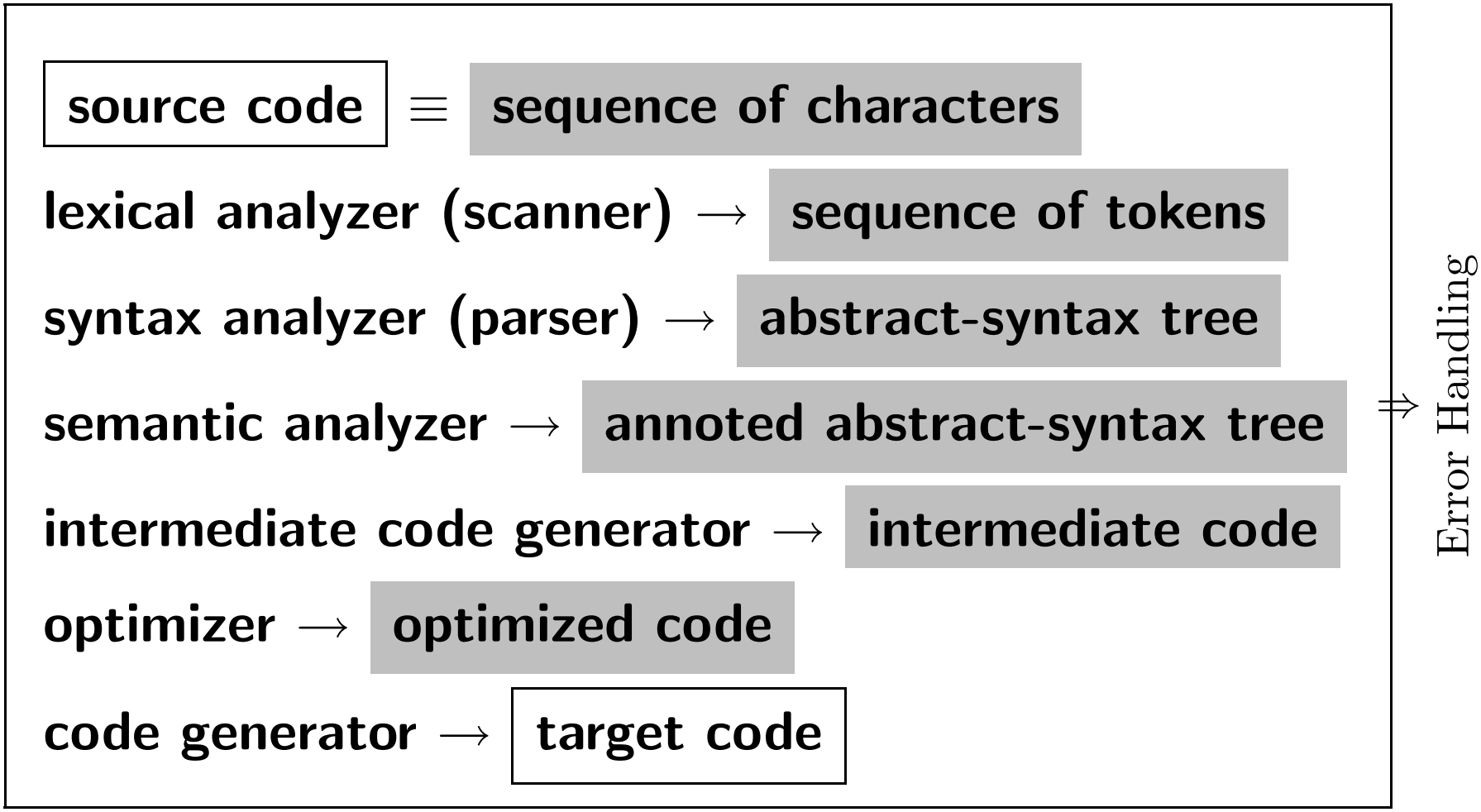
Applications

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

    ```
    3 + 5 - 6 * 6        ====>        3  5  + 6  6 * -
    ```

  - **pretty printers**
  - $\cdots$
- **Computational theory**
  - **power of certain machines**
    $\equiv$ the set of languages that can be recognized by this machine
  - **Grammar $\equiv$ definition of this machine**

Flow chart of a typical compiler



Scanner

- **Actions:**
  - **reads characters from the source program**
  - **groups characters into LEXEMES (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 for 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:**

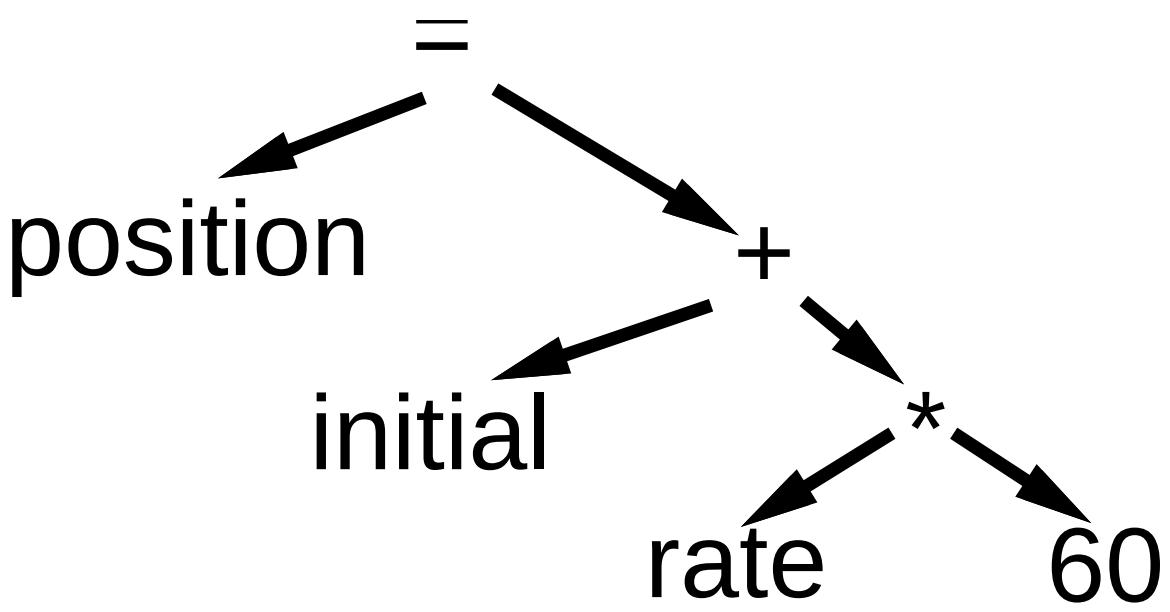
    (Lexeme) index = * 12 ;

    (Token) ID ASSIGN TIMES INT 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

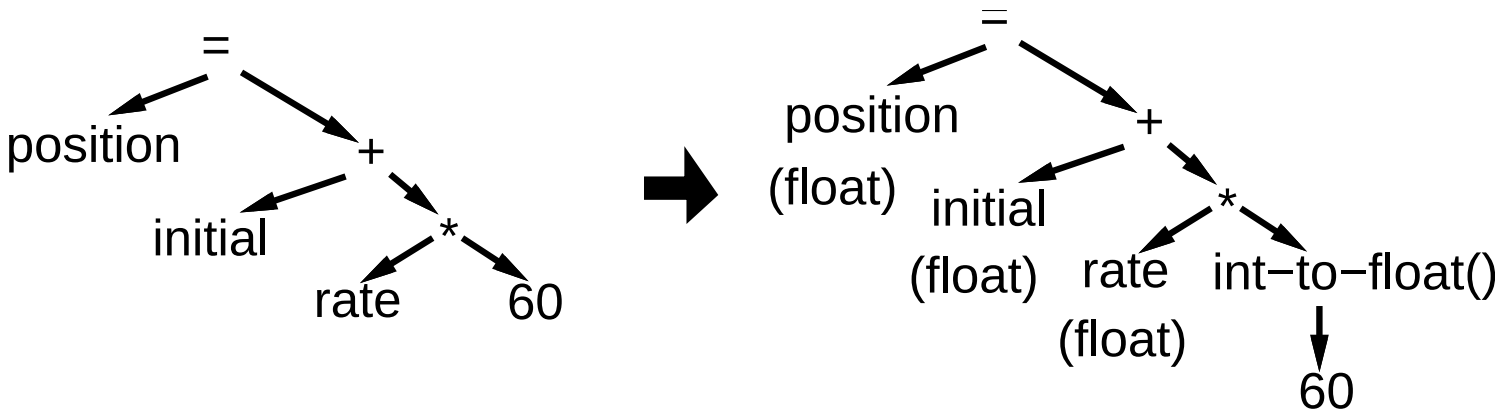
- **Source code:** **Position = initial + rate * 60;**
- **Abstract-syntax tree:**



- **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 multiplication has higher precedence than +, this operation must be performed as a unit, not "initial + rate".**

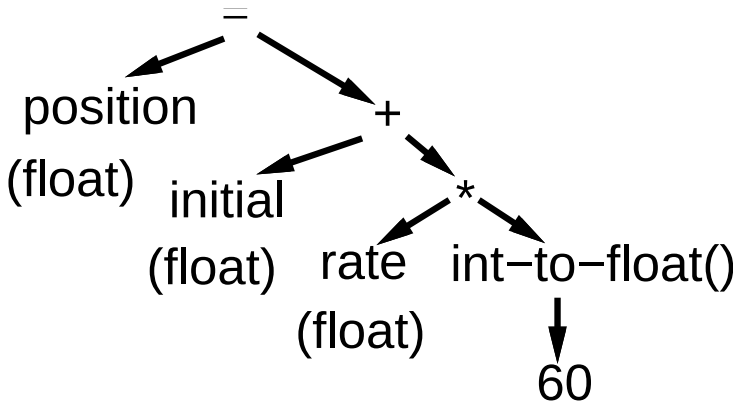
Semantic Analyzer

- **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 tree to intermediate code.**
- **One choice for intermediate code is 3-address code :**
  Each statement contains
  - **at most 3 operands;**
  - **in addition to ":=" (assignment), at most one operator**
  - **an"easy" and "universal" format to 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 make the code smaller.
- Example:

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

$\Longrightarrow$

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

- Current trend: obtain smaller, but maybe slower, equivalent code for embeded systems.

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*

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

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

Practical considerations II

- **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 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!**