Introduction to Compiler Construction

ASU Textbook Chapter 1

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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

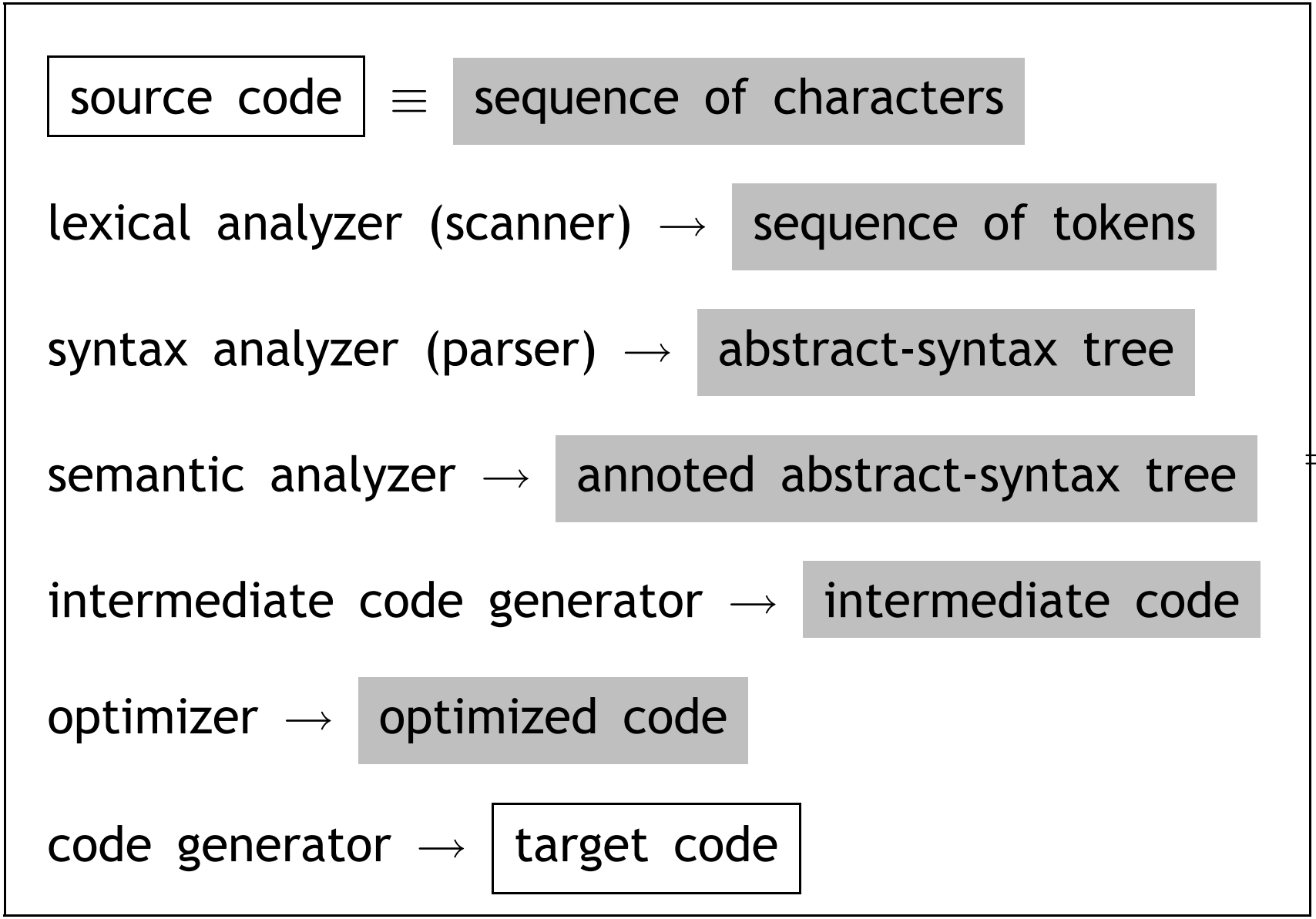
Applications

- 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
  - ...
- 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 LEXEMS (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:

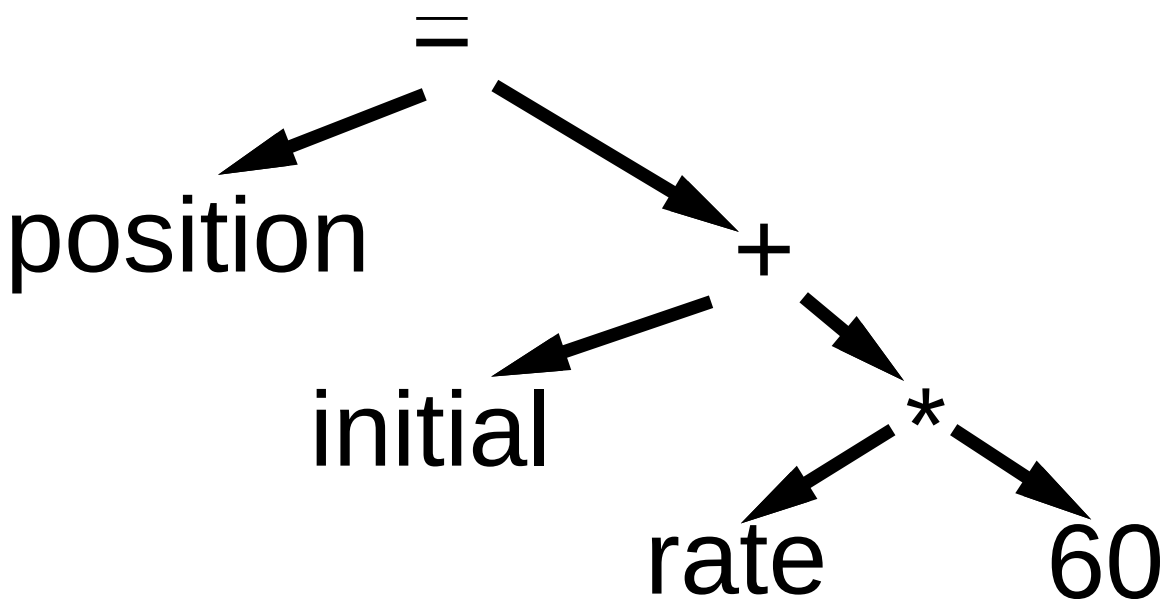
    (Lexeme) index = * 12 ;

    (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

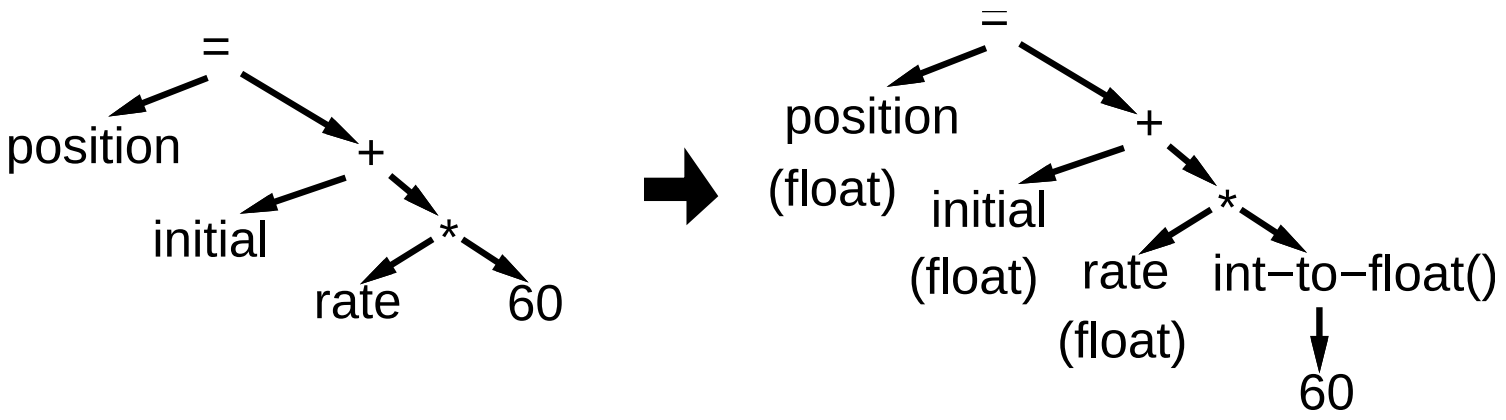
- Source code: Position = initial + rate * 60;
- Abstract-syntax tree:



- 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''.

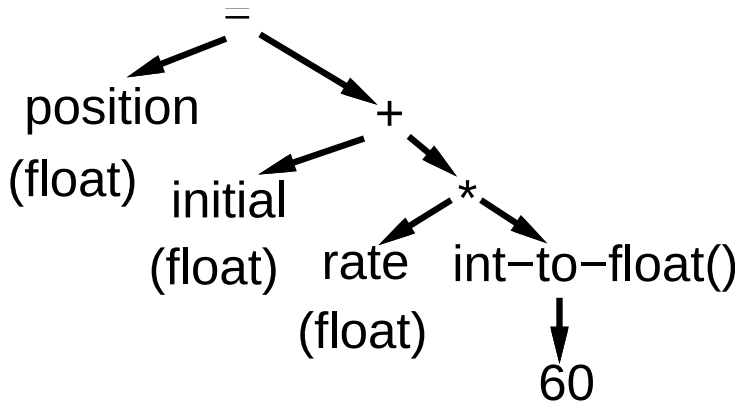
Semantic Analyzer

- 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:

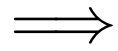



```
temp1 := int-to-float(60)

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
```



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

Code generation

- A compiler may generate
  - pure machine codes (machine dependent assembly language) directly, which is rare now .
  - virtual machine code
- Example:
  - PASCAL $\longrightarrow$ compiler $\longrightarrow$ P-code $\longrightarrow$ interpreter $\longrightarrow$ 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, R1
MULF    #60.0, R1
LOADF   initial, R2
ADDF    R2, R1
STOREF  R1, 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 encountered
  - check known labels
  - if not encountered before, then check this in to-be-processed table

  when a label is used
  - check whether it is defined
  - if not, save a trace into the to-be-processed table
- Time and Space trade-off!