Introduction to Compilers

Lecture 1

Objectives

By the end of this lecture you should be able to:

1. Identify the functions of different kinds of language processors.
2. Describe the structure of a typical compiler.
3. Identify the function of each component of a compiler.

Outline

1. Language Processors

2. The Structure of a Compiler

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Languages

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An alphabet is a non-empty, finite set of symbols.

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A string is a finite sequence of symbols over some alphabet.

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What are Languages Good for?

- Languages are used for
  1. representation
     - The language may be a private language of thought, for example.
  2. communication
     - The language must be a public communication language.
- In either case, strings in the language must be *meaningful*.
  - Whatever that means?

Programming Languages

- Programming languages are languages (sets of strings).
- Each string is a program.
- Programs are meaningful in that they describe computations which can be carried out by people and machines.
- The meaning of programs (semantics) lies in this transformation from programs (syntax) to structural configurations that cause actions.

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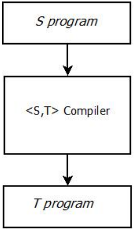
Machine Language

- A machine language is a language over the alphabet $\{0, 1\}$.
- A machine language program is a sequence of instructions.
- When loaded into the machine's instruction register, an instruction causes a unique behavior of the hardware.

Compilers



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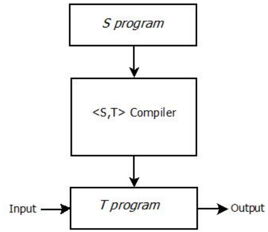
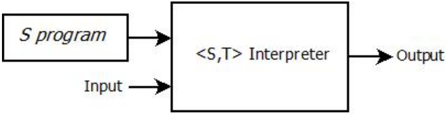
-

Compilers



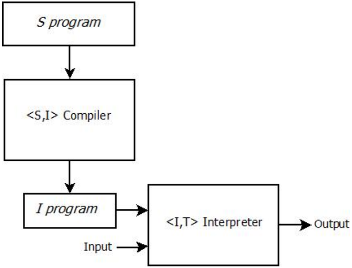
- A compiler is a software system which translates programs in a source language S into equivalent programs in a target language T.
- If T is the machine language of some machine M, then an $\langle S, T \rangle$ compiler makes S-programs meaningful for M.

Interpreters



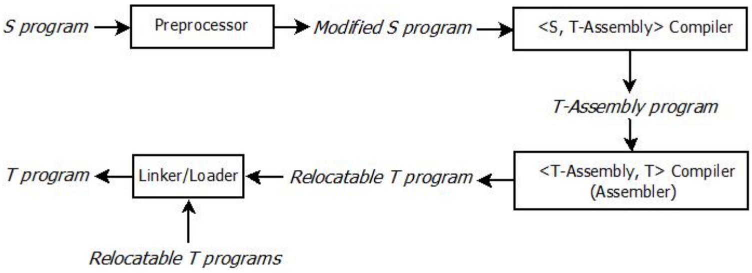
- Unlike a compiler, an interpreter does not produce a target program.
- It appears to be directly executing the source program on the input.
- Actually, it translates one statement of the S program into an equivalent piece of T program which is executed on the input.

Hybrid Compilers



- Sometimes, the S program is compiled into an intermediate I program, which is later interpreted by an $\langle I, T \rangle$ interpreter.
- For example, Java programs are compiled into bytecode, which is later interpreted by a virtual machine.

Structure of a General Language Processor

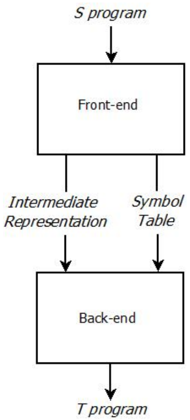


Outline

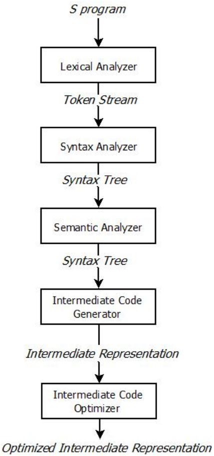
1. Language Processors
2. The Structure of a Compiler

Overall Structure

- The front-end of the compiler analyzes the S program into an intermediate representation.
- The back-end synthesizes the T program.
- The symbol table is a data structure containing a record for each identifier occurring in the S program.
  - What do you think is stored in these records?
- An $\langle S, T_1 \rangle$-compiler and an $\langle S, T_2 \rangle$-compiler may share the front-end. Similarly, An $\langle S_1, T \rangle$-compiler and an $\langle S_2, T \rangle$-compiler may share the back-end.



The Front-End



The Lexical Analyzer (I)

- Lexical analysis (or scanning)
  1. segments the input symbol stream into units called lexemes,
  2. identifies a certain class of symbols (or lexical category) of which the lexeme is a token, and
  3. produces a sequence of tokens of the form

$$\langle L, p \rangle$$

  where L is the name of a lexical category and p is a (possible) pointer to an entry for the token in the symbol table.

The Lexical Analyzer (II)

Example

- Segmentation: *How to recognize speech* vs. *How to wreck a nice peach*.
- Categorization: *How to recognize speech* $\Rrightarrow$ $[Adv, \{Prep, Part, Adv\}, V, N]$

Note that natural languages are lexically ambiguous.

The Lexical Analyzer (III)

Example

- Segmentation: "`position = initial + rate*60`" $\Rightarrow$ [`position`, `=`, `initial`, `+`, `rate`, `*`, `60`]
- Tokenization: $[\langle \textbf{id}, 1\rangle, \langle = \rangle, \langle \textbf{id}, 2\rangle, \langle + \rangle, \langle \textbf{id}, 3\rangle, \langle * \rangle, \langle \texttt{60} \rangle]$

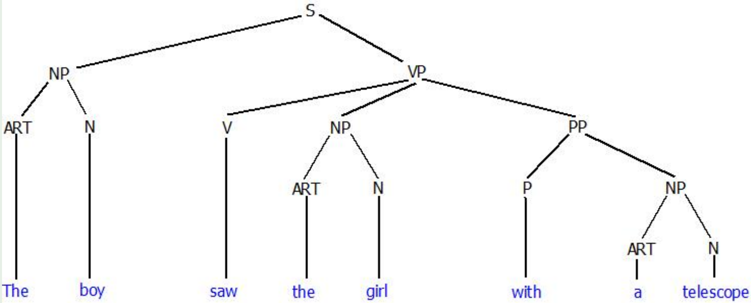
position	...
initial	...
rate	...

The Syntax Analyzer (I)

- Syntax analysis (or parsing) uncovers the recursive structure of a token stream by identifying meaningful sub-streams thereof.
- Typically, such structure is represented by a syntax tree.
- The syntax tree is often necessary for semantic interpretation.
- As an important side-effect, syntax analysis discovers grammatical errors.

The Syntax Analyzer (II)

Example



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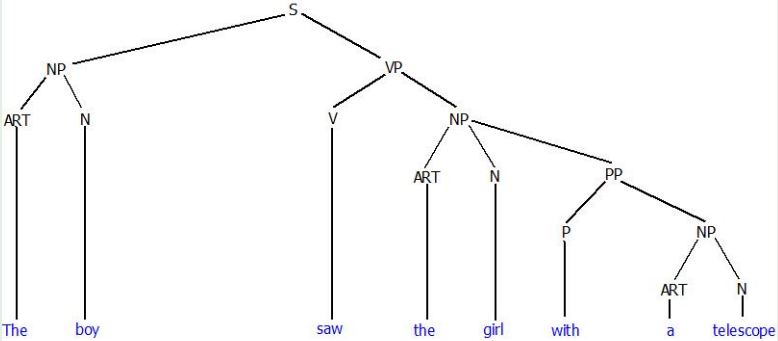
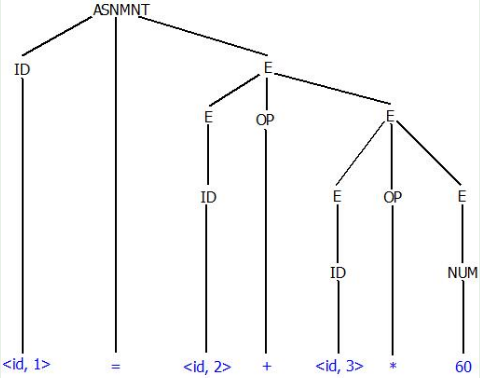


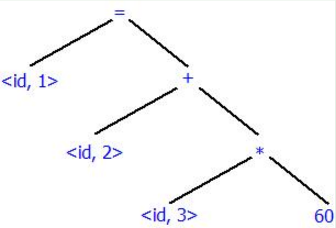
The Syntax Analyzer (IV)

Example



The Syntax Analyzer (V)

Example



Note that the tree indicates the order of evaluating expressions.

The Semantic Analyzer (I)

- The semantic analyzer makes sure that the input (program/sentence) is meaningful.
- English: *The boy saw the girl with a flower.*
- Programming languages: Type checking.

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The Semantic Analyzer (II)

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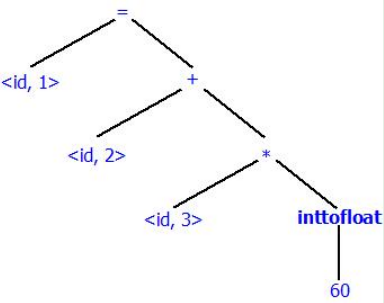

The Intermediate Code Generator (I)

- The intermediate representation should be
  1. easy to generate and
  2. easy to translate into the target language.

Example

Three-address code is a common intermediate representation:

- Assembly-like instructions.
- Each with at most three operands.
- Each with at most one operator and a single assignment.

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The Intermediate Code Generator (II)

Example

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

$$\Rrightarrow$$

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

Code Optimization (I)

- Code optimization attempts to transform the intermediate representation into a “better” target intermediate representation.
- “Better” may mean
  - faster,
  - shorter, or
  - less power-consuming.

Code Optimization (II)

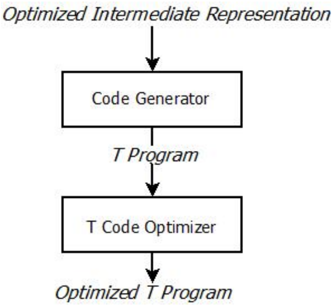
Example

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

$$\Rrightarrow$$

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

The Back-End (I)



The Back-End (II)

- The code generator translates the optimized intermediate representation into equivalent T code.
- If T is a machine language, registers or memory locations are allocated to the variables used.
- A carefully designed code generator needs to consider the crucial aspect of choosing variables that will be assigned to registers.
- The resulting T code may be further specifically optimized for the target machine.

The Back-End (III)

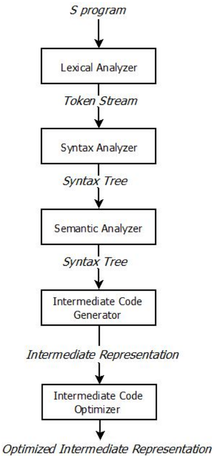
Example

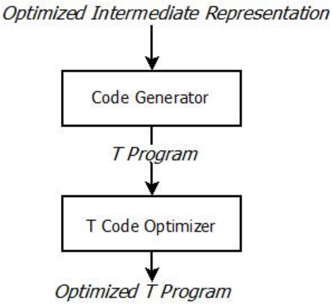
```
t1 = id3 * 60.0
id1 = id2 + t1
```

$\Rrightarrow$

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

Summary


S program
Lexical Analyzer
Token Stream
Syntax Analyzer
Syntax Tree
Semantic Analyzer
Syntax Tree
Intermediate Code Generator
Intermediate Representation
Intermediate Code Optimizer
Optimized Intermediate Representation


Optimized Intermediate Representation
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T Program
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