Introduction

Compilers are Translators

Source Code $\xrightarrow{\text{translate}}$ **Target Code**

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- C/C++
- Fortran
- Java
- PERL
- MATLAB
- Natural Language
- ...

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translate →

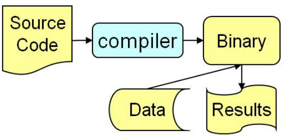
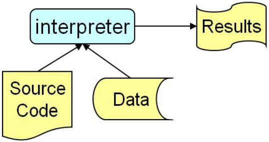
Target Code

- Machine Code
- Transformed Code (C, Java, ...)
- Virtual Machine Code
- Lower Level Commands
- Semantic Components
- ...

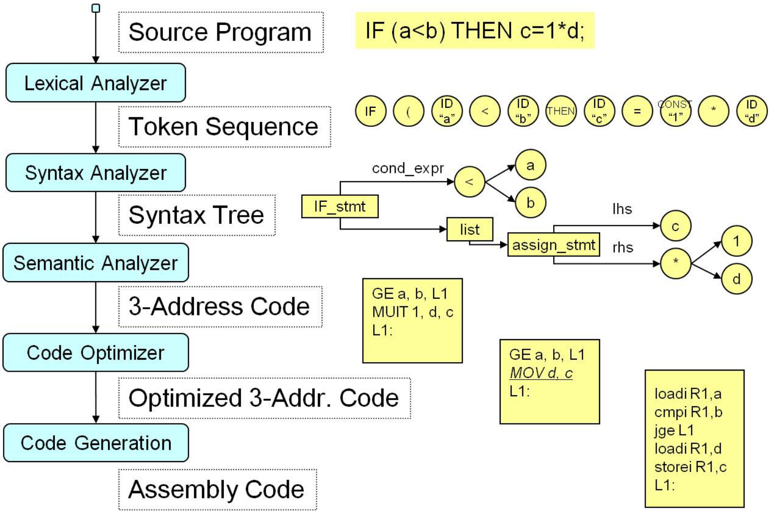
Translation Mechanisms

- Compilation
  - To translate a source program in one language into an executable program in another language and produce results while executing the new program
  - Examples: C, C++, FORTRAN
- Interpretation
  - To read a source program and produce the results while understanding that program
  - Examples: BASIC, LISP
- Hybrid
  - Case study: Java JVM
    (1) Translate source code to bytecode
    (2.a) Execute by interpretation on a JVM
    or
    (2.b) Execute by compilation using a JIT

Comparison of Compiler/Interpreter

	Compiler	Interpreter
Overview		
Advantages	Fast program execution; Exploit architecture features;	Machine independent; Easy to debug; Flexible to modify;
Disadvantages	Pre-processing of program; Complexity;	Execution overhead; Space overhead;

Phases of a Modern Compiler



Lexical and Syntax Analysis

- Lexical Analysis
  - Recognize token ? smallest unit over letters
  - Analyze input (strings of characters) from source
    - Scan from left to right
    - Report errors
- Syntax Analysis
  - Group tokens into hierarchy groups
    - Differentiate if-statement, while-statement, ...
    - Report errors

Semantic Analysis

- Determine the meaning using the structure
  - Checks are performed to ensure components fit together meaningfully
    - Information is added
    - Limited analysis to catch inconsistencies e.g. type checking
  - Put semantic meaningful items in the structure
    - Produce IR (intermediate representation)
    - Easier to generate machine code from IR

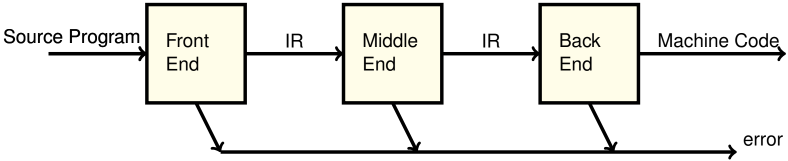
Code Optimization and Generation

- Code optimization: modify program representation so that program
  - Run faster
  - Use less memory
  - In general, reduce the consumed resources
- Code generation: produce target code
  - Instruction selection
  - Memory allocation
  - Resource allocation — registers, processors, etc.

Symbol Table Management

- Collect and maintain information about ids
  - Attributes: type, storage, scope, number, ...
- Used by most compiler passes
  - Phases to add information:
    lexical, parsing, semantic
  - Phases to use information:
    semantic, code optimization, code generation
- Debuggers use some form of symbol table
  - "gcc -g ..." keeps the symbol table in the object code

Traditional Three-pass Compilation



- Code Optimization
  - ➢ Analyzes IR and rewrites (or transforms) IR
  - ➢ Primary goal is to reduce running time of the compiled code
    - May also improve space, power consumption, ...
  - ➢ Must preserve “meaning” of the code
    - Measured by values of named variables

Distinction Between Phases and Passes

- Passes: number of times through a program representation
  - 1-pass, 2-pass, multi-pass compilation
  - Language becomes more complex — more passes
- Phases: conceptual and sometimes physical stages
  - Symbol table coordinates information between phases
  - Phases are not completely separate
    - Semantic phase may do things that syntax phase should do
    - Interaction is possible

Compiler Tools

- Automatic Generators

  Lexical Analysis —— Lex, Flex

  Syntax Analysis —— Yacc, Bison

  Semantic Analysis

  Code Optimization

  Code Generation

Compilers vs. Language Design

- There is a strong mutual influence
  - Hard to compile languages are hard to read
  - Easy to compile languages lead to quality compilers, better code, smaller compiler, more reliable, cheaper, wider use, better diagnostics
- Example: Dynamic Typing
  - seems convenient because type declaration is not needed

However,

- hard to read because the type of an identifier is not known
- hard to compile because the compiler cannot make assumptions about the identifier's type

Example: Dynamic Typing

- Is the following program correct?

```
int x=100;
function f() {
    string x;
    ...
  }
function g() {
    int * x;
    ...
  }
main() {
    ...
    if (...)
        f();
    else
        g();
    x=x+1;
    strcpy(x, "test");
  }
```

Compilers vs. Computer Architecture Influence

- Complex instructions were available when programming at assembly level
  - CISC: Complex Instruction Set Computing
- RISC architecture became popular with the advent of high-level languages
  - RISC: Reduced Instruction Set Computing
  - Why is RISC preferred by a compiler?
- Today, the development of new instruction set architectures (ISA) is heavily influenced by compilation advances
  - MMX: Multimedia Instruction Set Extension
  - NP: Network Processors

Computer Architecture Influence

- Von Neumann Architecture
  - Well-known, widely used
- Imperative languages, most dominant, because of von Neumann computers
  - Data and programs stored in memory
  - Memory is separate from CPU
  - Instructions and data are piped from memory to CPU
  - Basis for imperative languages
    - Variables model memory cells
    - Assignment statements model piping
    - Iteration is efficient

Example: MMX

- Multimedia applications need to process byte stream intensively
  - Spend most of its time in byte data computation
- RISC machine need to load the data to registers before computation
  - Register R1, R2, R3, ... are 32-bit or 64-bit registers