# CS 1622:
# Introduction to Compiler Design

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## What is a Compiler?

A **compiler** translates a source specification into a target specification.

Traditionally, we consider compilers that take a source language and produce target (machine) code. However, there can be many different types of targets.

| Source Language | | Target Language |
|---|---|---|
| C/C++ | → | Machine code |
| Java | → | Java Bytecode |
| Perl | → | Perl Bytecode |
| Java Bytecode | → | Machine code |

## Compilers vs. Interpreters

**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

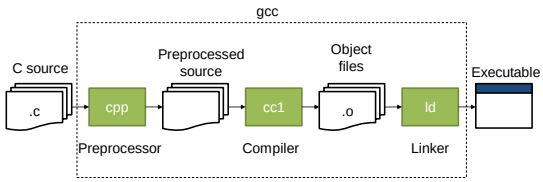
**Hybrid –** Try to use both (such as in Java)

1. Translate source code to bytecode
2. Execute by interpretation on a JVM

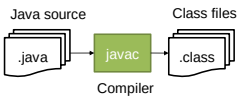
*or*

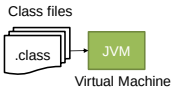
2. Execute by compilation using a JIT

## C Compiler

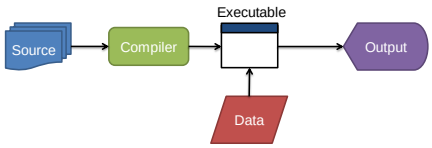



## Java Compiler




## Compilation



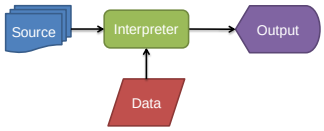

**Pros:**

- Fast execution
- Can exploit machine architecture features

**Cons:**

- Complexity
- Must be done before execution

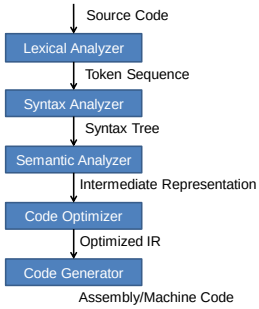
# Interpreter




**Pros:**
- Machine independent
- Easy to debug
- Flexible to modify

**Cons:**
- Time overhead
- Space overhead

# Phases of Compilation




# Phases

**Lexical Analysis**
- Recognize token – smallest stand-alone unit of meaningful information
- Analyze input (strings of characters) from source
  - Scan from left to right
  - Report errors

**Syntax Analysis**
- Group tokens into hierarchical 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
  - Limited analysis to catch inconsistencies, e.g., type checking
- Put semantic meaningful items in the structure
  - Produce IR (easier to generate optimized machine code from IRs)

# Phases

**Code optimization**
- Modify program representation so that program:
  - Runs faster
  - Uses less memory
  - Uses less power
- In general, reduce the consumed resources

**Code generation**
- Produce target code
  - Instruction selection
  - Memory allocation
  - Resource allocation — registers, processors, etc.

# Lexing

**Input:** Source program
**Output:** Sequence of **tokens**

**Example:**

```
if(x > 3)
{
        y++;
}
```

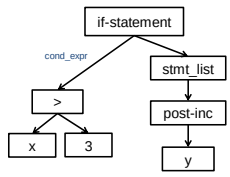
| IF | ( | ID('x') | > | NUM('3') | ) | { | ID('y') | INCREMENT | ; | } |
|---|---|---|---|---|---|---|---|---|---|---|

# Parsing

**Input:** Sequence of tokens
**Output:** **Abstract Syntax Tree**

**Example:**

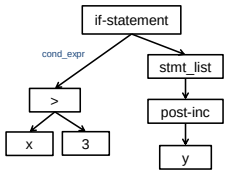
| IF | ( | ID('x') | > | NUM('3') | ) | { | ID('y') | INCREMENT | ; | } |
|---|---|---|---|---|---|---|---|---|---|---|



# Code Generation

**Input:** Intermediate representation
**Output:** Target code

**Example:**



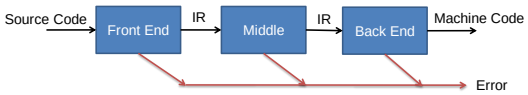

```
        slti   $t1, 3, $s0
        beq    $t1, $zero, L1
        addi   $s1, $s1, 1
L1:
```

# Data Structures for Compilation

**Abstract Syntax Tree**
- Stores the information from the parse and lexing phases
- Walk the tree to produce IR or target code

**Symbol Table**
- Collect and maintain information about identifiers
  - Attributes: type, address, scope, size
- Used by most compiler passes and phases
  - Some phases add information:
    - lexing, parsing, semantic analysis
  - Some phases use information:
    - Semantic analysis, code optimization, code generation
- Debuggers also can make use of a symbol table
  - `gcc -g` keeps a version of the symbol table in the object code

# Three-pass Compiler




**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 Construction

Automatic Generators:
- Lexical Analysis — Lex, Flex, JLex, JFlex
- Syntax Analysis — Yacc, Bison, JavaCUP, JavaCC
- Semantic Analysis
- Code Optimization
- Code Generation