CSC402 Programming Language Implementation

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Welcome!

Course Objectives

- Provide a solid foundation with respect to programming language implementation including
  - grammar construction
  - parsing techniques,
  - intermediate representations (tree construction, pattern matching and tree walking techniques)
  - symbol table construction
  - code generation
- We will study a number of different programming language implementation techniques including compilers, interpreters, and virtual machines.
- You can add <u>domain specific</u> and <u>general programming</u> language implementations to your tool chest.

Textbook

- Online Textbook
  - See BrightSpace

Some Definitions

- Domain Specific Language (DSL)
  - In software development a DSL is a programming language or specification language dedicated to a particular problem domain, a particular problem representation technique, and/or a particular solution technique.‡
  - Examples: Html, MSDOS/Linux shell scripts, game engine scripting languages

‡ Wikipedia

Some Definitions

- General (Purpose) Programming Language[‡]
  - A general purpose programming language is a programming language designed to be used for writing software in a wide variety of application domains.
  - In many ways a general purpose language only has this status because it does not include language constructs designed to be used within a specific application domain (e.g., a page description language contains constructs intended to make it easier to write programs that control the layout of text and graphics on a page).

‡ Wikipedia

Some Definitions

- High-Level Programming Language
  - A language that supports data abstraction and "structured programming"
  - e.g. class definitions and while-loops, if-then-else statements
- Low-Level Programming Language
  - A language that does NOT support data abstraction and "structured programming"
  - Most assembly languages and bytecodes fall into this category

The Structure of Programming Languages

- A programming language is a formal system of symbols that are combined to make up larger structures according to certain rules – **the Syntax of a Programming Language**
- The combination of symbols and the larger structures carry information which language processors need to decode.
- We will see that the architecture of language processors is geared towards extracting this information by accessing the hierarchy of symbols and structures embedded in programming languages – **Syntax Analysis**

The Structure of Programming Languages

The hierarchy (low to high):

symbol (character)
word (token)
phrase
sentence

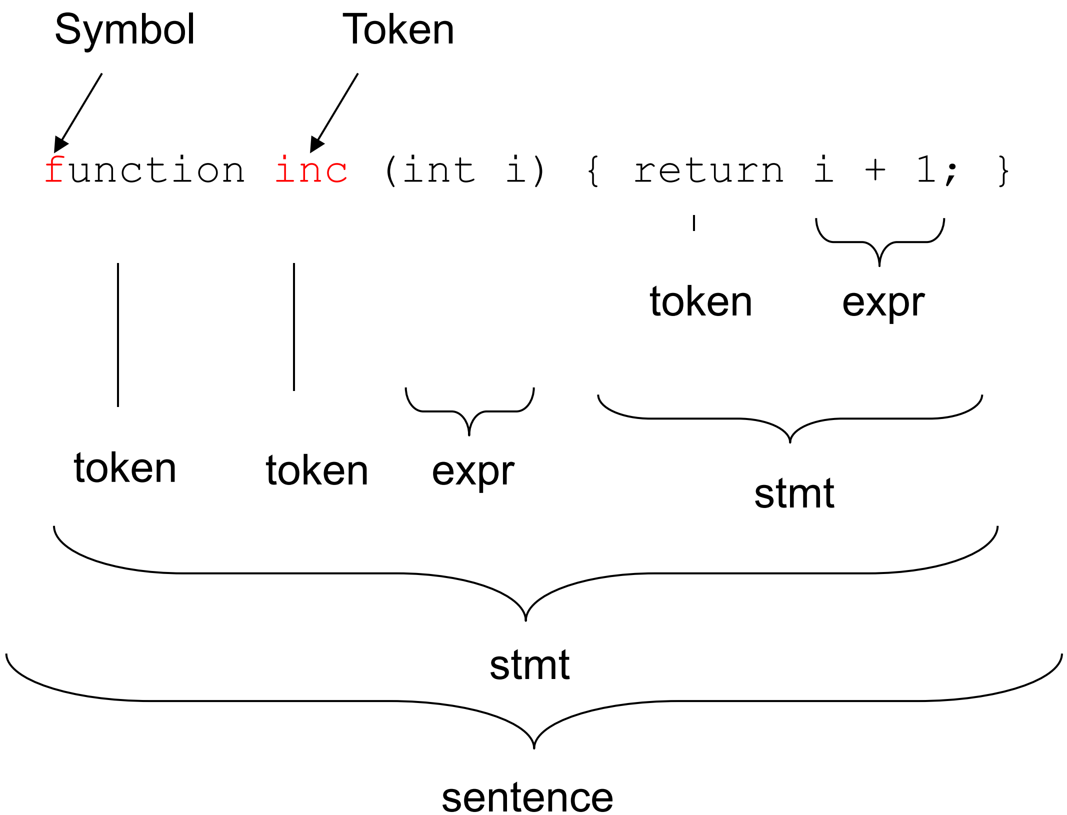
Symbols are combined to form words, words are combined to form phrases, and phrases are combined to form sentences.

A programming language is a collection of valid sentences; a sentence is valid if the symbols, words, and phrases are combined according to the rules of the language.

These rules are usually specified using a grammar (more on that later)

The Structure of Programming Languages

An Example: Function Definition



- a function definition is a sentence, this sentence is a stmt
- the stmt is composed of two tokens (function, inc), an expr, and a stmt
- the expr is composed of four tokens: (,),int,i
- the stmt is composed of a token (return) and an expr
- the expr is composed of three tokens: I, +, 1

☞ Language processors are built to extract this kind of hierarchy and process it.

Note: the structure of a language is also called the syntax.

The Structure of Programming Languages

- Programming text page vs. Symbol Stream
  - We usually represent programs as 2D text

```
i=0
while i < 10 do
      print i
      i=i+1
enddo
```

  - However, to the language processor this appears to be just a stream of symbols:

```
i=0<cr>while<sp>i<sp><<sp>10<sp>do<cr><tab>print<sp>i<cr>…
```

  - Here, <cr>, <sp>,and <tab> are special symbols

The Behavior of Programming Languages

- In addition to specifying the syntax of a programming language we also need to specify its behavior – **the Semantics of the Language**
- Every programmer instinctively knows what the following program fragment does:

```
i=0
while i < 10 do
      print i
      i=i+1
enddo
```

- But we need to tell the language processor what this program means; how it should behave.

The Behavior of Programming Languages

Example of a specification:

Syntax:

WhileStatement:

while *Expression* **do** *Statement* **enddo**

Semantics:

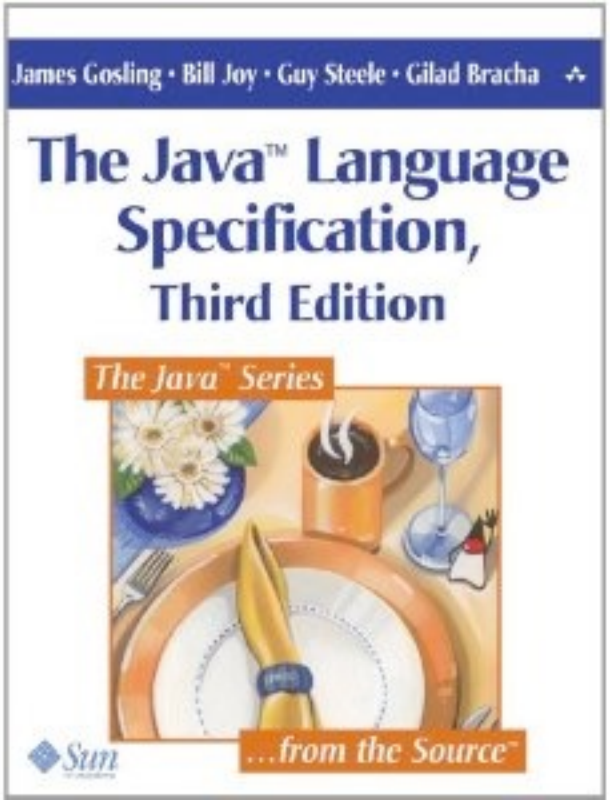
The while statement executes an *Expression* and a *Statement* repeatedly until the value of the *Expression* is false.

The *Expression* must have type Boolean, or an error occurs.

A while statement is executed by first evaluating the *Expression*:

1. If the value is *true*, then the contained *Statement* is executed. If execution of the *Statement* completes normally, then the entire while statement is executed again, beginning by re-evaluating the *Expression*.
2. If the value is *false*, no further action is taken and the while statement terminates.

The Behavior of Programming Languages



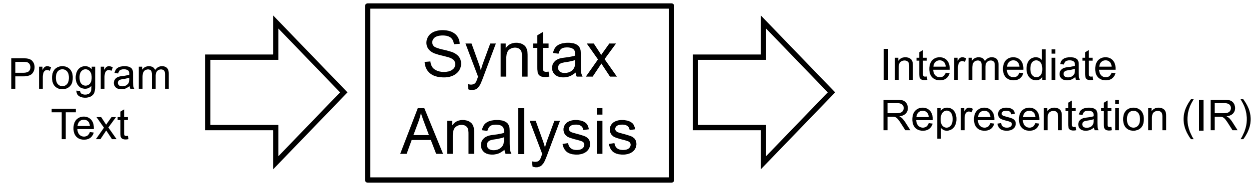
- The specification of general purpose programming languages can be very complex.
- In the case of Java this is a 700 page book!
- Domain specific programming languages tend to be less complex and therefore much easier and faster to implement.

The Java Language Specification, Gosling, Joy, Steele, Bracha, 3rd edition, Wiley, 2005.

Building Blocks of Language Processors

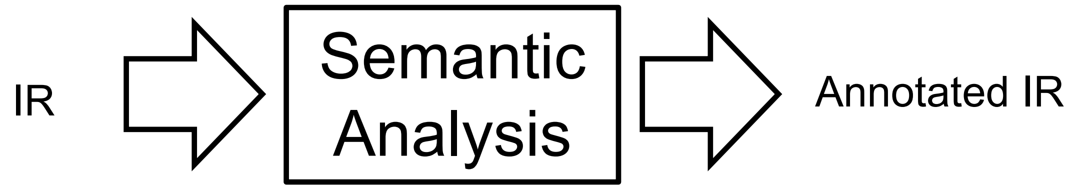
- Most programming language processors are made up of one or more three main building blocks:
  - Syntax Analysis – program text/structure analysis
  - Semantic Analysis – program behavior analysis
  - Code Generation

Syntax Analysis



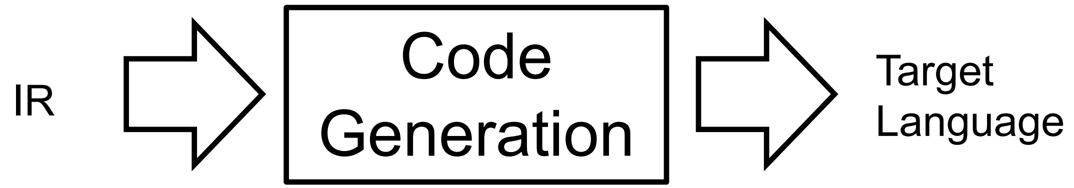
- The syntax analysis reads the program text and produces an intermediate representation (IR)
- The IR is an **abstract representation** of the program text

Semantic Analysis



- The semantic analysis reads the IR and analyzes the encoded behavior
- The semantics analysis typically outputs an annotated version of the IR
- These annotations insure the correct behavior of the program, for example, memory space for a declared variable.

Code Generation

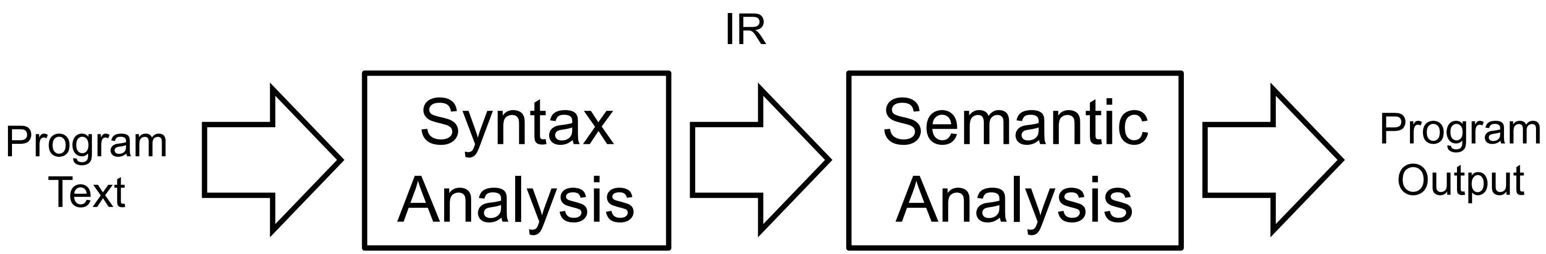


- The semantic analysis reads the IR and translates it into the target language
- The target language could be a high level language, assembly code, or byte code.
- The target code can also be a spreadsheet that summarizes data described with the IR, etc.

The Structure of Language Processors

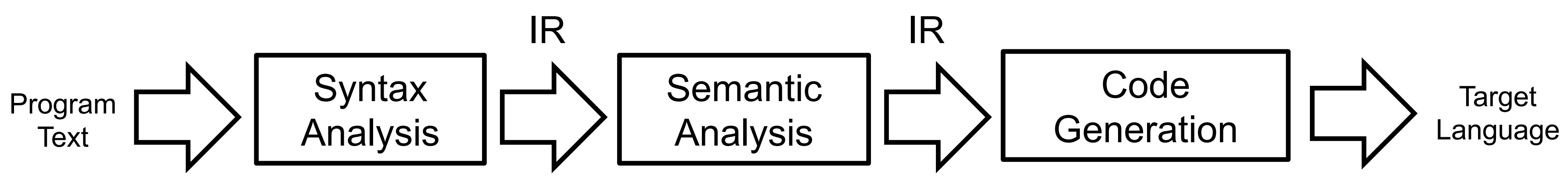
- We can now plug these building blocks together in different configuration in order to obtain a variety of language processors.
- In particular, we can configure these building blocks as:
  - Interpreter
  - Translator/Compiler
  - Simple Translator

The Interpreter



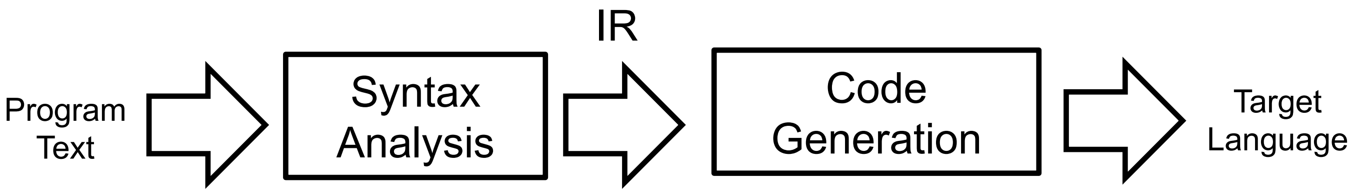
- An interpreter is made up of a syntactic and a semantic analysis block.
- An interpreter reads, decodes, and executes code.
- For interpreters the semantic analysis block is slightly modified – it analyzes and **executes** the IR producing the program output.
- Examples include simple programmable calculators as well as languages such as Ruby and Python.

The Translator/Compiler



- A translator consists of all three of our building blocks.
- A translator reads text in one language and emits output conforming to another language.
- We often fit an additional optimization phase between the semantic analysis and the code generation phases.
- Examples include log file generators, assemblers and of course compilers.
- Note: A compiler is a translator that translates a high-level language to a low-level language.

The Simple Translator



- A simple translator consists of a syntax analysis block and a code generation block
- It does not perform any semantic analysis
- Think of it as the Reader followed by the Generator.
- Examples include pretty printers and other formatters.

Example: Processing the Java Language

- A processing pipeline for a language can consist of multiple language processors.
- The language processing pipeline for Java consists mainly of
  - A compiler from Java to bytecode
  - A bytecode interpreter

Example: Processing the Java Language

Java:

```
class Funny {

    public int i = 0;

    public Funny(int x) {
        i = x;
    }

    public static void main(String[] args) {
        Funny a[] = new Funny[10];

        for (int j = 0; j < 10; j++) {
            a[j] = new Funny(j);
        }
    }
}
```

compile

Program Output

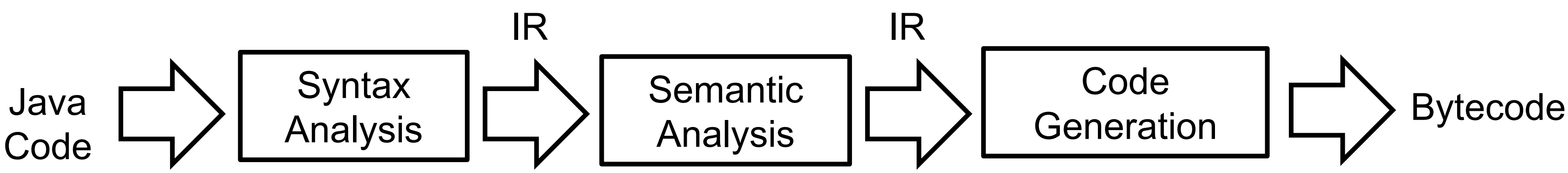
interpret

Bytecode:

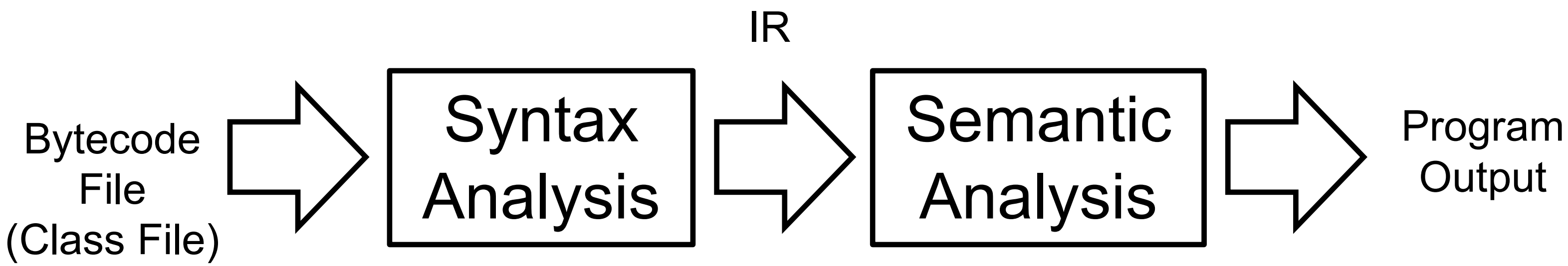
```
class Funny extends java.lang.Object{
public int i;
public Funny(int);
  Code:
   0:   aload_0
   1:   invokespecial   #1; //Method java/lang/Object."<init>":()V
   4:   aload_0
   5:   iconst_0
   6:   putfield        #2; //Field i:I
   9:   aload_0
   10:  iload_1
   11:  putfield        #2; //Field i:I
   14:  return
public static void main(java.lang.String[]);
  Code:
   0:   bipush  10
   2:   anewarray       #3; //class Funny
   5:   astore_1
   6:   iconst_0
   7:   istore_2
   8:   iload_2
   9:   bipush  10
   11:  if_icmpge       31
   14:  aload_1
   15:  iload_2
   16:  new     #3; //class Funny
   19:  dup
   20:  iload_2
   21:  invokespecial   #4; //Method "<init>":(I)V
   24:  aastore
   25:  iinc    2, 1
   28:  goto    8
   31:  return
}
```

Note: javap -c <classname> will show bytecode.

Example: Processing the Java Language - Compiler



Example: Processing the Java Language – Bytecode Interpreter



Assignments & Readings

- Read Chapter 1
- Assignment #0:
  - Download & Read Syllabus
  - upload a copy into BrightSpace