

## Programming Assignment IV

Assigned: February 29

Due: March 28 at 11:59 PM

## 1 Introduction

In this assignment, you will implement the static semantics of Cool. You will use the abstract syntax trees (AST) built by the parser to check that a program conforms to the Cool specification. Your static semantic component should reject erroneous programs; for correct programs, it must gather certain information for use by the code generator. The output of the semantic analyzer will be an annotated AST for use by the code generator.

This assignment has much more room for design decisions than previous assignments. Your program is correct if it checks programs against the specification. There is no one “right” way to do the assignment, but there are wrong ways. There are a number of standard practices that we think make life easier, and we will try to convey them to you. However, what you do is largely up to you. Whatever you decide to do, be prepared to justify and explain your solution.

You will need to refer to the typing rules, identifier scoping rules, and other restrictions of Cool as defined in the Cool Reference Manual. You will also need to add methods and data members to the AST class definitions for this phase. The functions the tree package provides are documented in the javadoc included in the package (see [javadoc/index.html](#)).

There is a lot of information in this handout, and you need to know most of it to write a working semantic analyzer. *Please read the handout thoroughly.* At a high level, your semantic checker will have to perform the following major tasks:

1. Look at all classes and build an inheritance graph.
2. Check that the graph is well-formed.
3. For each class
  - (a) Traverse the AST, gathering all visible declarations in a symbol table.
  - (b) Check each expression for type correctness.
  - (c) Annotate the AST with types.

This list of tasks is not exhaustive; it is up to you to faithfully implement the specification in the manual.

You may work in a group of one or two people. The submit program will ask you to specify group members when you turn in your assignment.

## 2 Files and Directories

Everything you need is included in the archive file (PA4.zip) available from the course website. This package contains a number of files. Some of the files (Java files) should not be edited. In fact, if

you modify these files, you may find it impossible to complete the assignment. See the instructions in the README file.

## 2.1 Files to modify

The files that you will need to modify are:

- `cool-tree.java`  
This file contains the definitions for the AST nodes and is the main file for your implementation of the semantic analysis phase. You will need to add the code for your semantic analysis phase in this file. The semantic analyzer is invoked by calling method `semant()` of class `program`. Do **not** modify the existing declarations.
- `ClassTable.java`  
This class is a placeholder for some useful methods (including error reporting and initialization of basic classes). You may wish to enhance it for use in your analyzer.
- `TreeConstants.java`  
This file defines some useful symbol constants.
- `good.cl` and `bad.cl`  
These files test a few semantic features. You should add tests to ensure that `good.cl` exercises as many legal semantic combinations as possible and that `bad.cl` exercises as many kinds of semantic errors as possible. It is not possible to exercise all possible combinations in one file; you are only responsible for achieving reasonable coverage. Explain your tests in these files and put any overall comments in the README file.
- `README`  
This file will contain the write-up for your assignment. For this assignment it is critical that you explain **design decisions**, **how** your code is structured, and **why** you believe that the design is a good one (i.e., why it leads to a correct and robust program). It is part of the assignment to explain things in text as well as to comment your code. Inadequate README files will be penalized more heavily in this assignment, as the README is the major guideline we have to understanding your code.

## 2.2 Helper scripts

The assignment package includes several scripts to easily compile and run your semantic analyzer (and the reference implementation as well). The following is the list of commands you can run:

- To compile the example use of the symbol table: `ant symtab-example`
- To compile your parser implementation: `ant semant`
- To run your semantic analyzer on the file `good.cl` and `bad.cl`: `ant test`
- To run ten examples in tests directory: `ant test-all`
- To run your semantic analyzer on an input file `'foo.cl'`: `python mysemant.py foo.cl`

- To compile a program ‘foo.cl’ with your semantic analyzer and the rest of the reference compiler: `python mycoolc.py foo.cl`
- To run the reference semantic analyzer on an input file ‘foo.cl’ : `python semant.py foo.cl`
- To compile a program ‘foo.cl’ with the reference compiler and to generate ‘foo.s’: `python coolc.py foo.cl`
- To run the compiled program ‘foo.s’ using the MARS mips simulator: `python runmips.py foo.s`
- To compare your semantic analyzer and the reference analyzer on an input file ‘foo.cl’: `python compare-semant.py foo.cl`

## 2.3 Using your own machine

If you want to use your own machine for the development, you will need to install JDK 7, Apache Ant 1.7 (or newer), and Python 2.7. You can get the packages from the following links:

- JDK 7: <http://www.oracle.com/technetwork/java/javase/downloads/jdk7-downloads-1880260.html>
- Apache Ant: <http://ant.apache.org/bindownload.cgi>
- Python 2.7.11: <https://www.python.org/downloads/>

After installing a package, please put the path to the bin folder of the installed package in your `PATH` variable. In other words, `java`, `javac`, `ant`, and `python` commands should run on the shell prompt without the exact path to the corresponding bin folder. You also need to set `JAVA_HOME` and `ANT_HOME` environment variables.

**Mac and Linux.** You can also use a package manager for your system, such as `apt-get` and `brew`, to install a necessary package. Just make sure that you are using the correct version. Package managers do not set `JAVA_HOME` and `ANT_HOME` environment variables for you. So, please make sure to set these variables.

**Windows.** Please check the following guides to setup a development environment on a Windows machine:

- *JDK installation:* <http://docs.oracle.com/javase/7/docs/webnotes/install/windows/jdk-installation-windows.html>
- *Setting the JAVA\_HOME Variable:* [https://confluence.atlassian.com/doc/setting-the-java\\_home-variable-in-windows-8895.html](https://confluence.atlassian.com/doc/setting-the-java_home-variable-in-windows-8895.html)
- *Python on Windows:* <https://docs.python.org/2/using/windows.html>
- *Installing Apache Ant:* <http://ant.apache.org/manual/install.html>

### 3 Tree Traversal

As a result of assignment 3, your parser builds abstract syntax trees. The method `dump_with_types`, defined on most AST nodes, illustrates how to traverse the AST and gather information from it. This algorithmic style—a recursive traversal of a complex tree structure—is very important, because it is a very natural way to structure many computations on ASTs.

Your programming task for this assignment is to (1) traverse the tree, (2) manage various pieces of information that you glean from the tree, and (3) use that information to enforce the semantics of Cool. One traversal of the AST is called a “pass”. You will probably need to make at least **two passes over** the AST to check everything.

You will most likely need to attach customized information to the AST nodes. To do so, you may edit `cool-tree.java` directly.

### 4 Inheritance

Inheritance relationships specify a directed graph of class dependencies. A typical requirement of most languages with inheritance is that the inheritance graph be **acyclic**. It is up to your semantic checker to enforce this requirement. One fairly easy way to do this is to construct a representation of the type graph and then check for cycles.

In addition, Cool has restrictions on inheriting from the **basic** classes (see the manual). It is **also** an **error** if class A inherits from class B but class B is not defined.

The project skeleton includes appropriate definitions of all the basic classes. You will need to incorporate these classes into the inheritance hierarchy.

We suggest that you divide your semantic analysis phase into two smaller components. **First**, check that the inheritance graph is well-defined, meaning that all the restrictions on inheritance are satisfied. If the inheritance graph is not well-defined, it is acceptable to **abort** compilation (after printing appropriate error messages, of course!). **Second**, check all the other semantic conditions. It is much easier to implement this second component if one knows the inheritance graph and that it is legal.

### 5 Naming and Scoping

A major portion of any semantic checker is the management of names. The specific problem is determining which declaration is in effect for each use of an identifier, especially when names can be reused. For example, if `i` is declared in two `let` expressions, one nested within the other, then wherever `i` is referenced the semantics of the language specify which declaration is in effect. It is the job of the semantic checker to keep track of which declaration a name refers to.

As discussed in class, a **symbol table** is a convenient data structure for managing names and scoping. You may use our implementation of symbol tables for your project. Our implementation provides methods for entering, exiting, and augmenting scopes as needed. You are also free to implement your own symbol table, of course.

Besides the identifier **self**, which is implicitly bound in every class, there are four ways that an object name can be introduced in Cool:

- attribute definitions;
- formal parameters of methods;

- let expressions;
- branches of case statements.

In addition to object names, there are also `method` names and `class` names. It is an error to use any name that has no matching declaration. In this case, however, the semantic analyzer should *not* abort compilation after discovering such an error. Remember that neither classes, methods, nor attributes need be declared before use. Think about how this affects your analysis.

## 6 Type Checking

Type checking is another major function of the semantic analyzer. The semantic analyzer must check that valid types are declared where required. For example, the return types of methods must be declared. Using this information, the semantic analyzer must also verify that every expression has a valid type according to the type rules. The type rules are discussed in detail in the Cool Reference Manual and the course lecture notes.

One difficult issue is what to do if an expression doesn't have a valid type according to the rules. **First**, an `error` message should be printed with the line number and a description of what went wrong. It is relatively easy to give informative error messages in the semantic analysis phase, because it is generally obvious what the error is. We expect you to give informative error messages. **Second**, the semantic analyzer should attempt to `recover` and continue. We do expect your semantic analyzer to recover, but we do not expect it to avoid cascading errors. A simple recovery mechanism is to assign the type `Object` to any expression that cannot otherwise be given a type (we used this method in `coolc`).

## 7 Code Generator Interface

For the semantic analyzer to work correctly with the rest of the `coolc` compiler, some care must be taken to adhere to the interface with the code generator. We have deliberately adopted a very simple, naïve interface to avoid cramping your creative impulses in semantic analysis. However, there is one thing you must do. For every expression node, its `type` field must be set to the `Symbol` naming the type inferred by your type checker. This `Symbol` must be the result of the `addString` method of the `idtable`. The special expression `no_expr` must be assigned the type `No_type` which is a predefined symbol in the project skeleton.

## 8 Expected Output

For incorrect programs, the output of semantic analysis is error messages. **You** are expected to recover from all errors except for ill-formed class hierarchies. **You** are **also** expected to produce complete and informative errors. Assuming the inheritance hierarchy is well-formed, the semantic checker should catch and report all `semantic` errors in the program. Your error messages need not be identical to those of `coolc`.

We have supplied you with simple error reporting methods `PrintStream ClassTable.semantError(class_)`. This routine takes a `class_` node and returns an output stream that you can use to write error messages. Since the parser ensures that `class_` nodes store the file in which the class was defined (recall that class definitions cannot be split across files), the

line number of the error message can be obtained from the AST node where the error is detected and the filename from the enclosing class.

For correct programs, the output is a type-annotated abstract syntax tree. You will be graded on whether your semantic phase correctly annotates ASTs with types and on whether your semantic phase works correctly with the `coolc` code generator.

## 9 Testing the Semantic Analyzer

You will run your semantic analyzer using `mysemant.py`, a shell script that “glues” together the analyzer with the reference parser and the reference scanner. Note that `mysemant.py` takes a `-s` flag for `debugging` the analyzer; using this flag merely causes `semant_debug` (a static field of class `Flags`) to be set. Adding the actual code to produce useful debugging information is up to you. See the project README for details.

Once you are confident that your semantic analyzer is working, try running `mycoolc.py` to invoke your analyzer together with other compiler phases. You should test this compiler on both good and bad inputs to see if everything is working. Remember, bugs in the semantic analyzer may manifest themselves in the code generated or only when the compiled program is executed.

## 10 Implementation Note

The semantic analysis phase is by far the largest component of the compiler so far. Our solution is approximately 900 lines of Java. You will find the assignment easier if you take some time to design the semantic checker prior to coding. Ask yourself:

- What requirements do I need to check?
- When do I need to check a requirement?
- When is the information needed to check a requirement generated?
- Where is the information I need to check a requirement?

If you can answer these questions for each aspect of Cool, implementing a solution should be straight-forward.

## 11 Final Submission

Make sure to complete the following items before submitting to avoid any penalties.

- ☐ Include your write-up in README.
- ☐ Include your test cases that should pass the semantic analyzer in `good.cl` and your test cases that should cause the semantic analyzer to issue an error in `bad.cl`.
- ☐ Make sure all your code for the semantic analyzer is in
  - `cool-tree.java`, `ClassTable.java`, `TreeConstants.java`, and additional `.java` files you may have added.
- ☐ Be sure to answer ‘yes’ to the submission prompt for files that contain your code.

**Grading (out of 100 points)** The point breakdown for the final submission of PA4 is as follows:

- 76 points - for autograder tests
- 8 points for the README
  - 8 - thorough discussion of design decisions and choice of test cases; a few paragraphs of coherent English sentences should be fine
  - 4 - vague or hard to understand; omits important details
  - 0 - little to no effort
- 8 points - for `good.cl` and `bad.cl`
  - 8 - wide range of test cases added
  - 4 - added some tests, but the scope not sufficiently broad
  - 0 - little to no effort
- 8 points - for code cleanliness
  - 8 - code is mostly clean and well-commented
  - 4 - code is sloppy and/or poorly commented in places
  - 0 - little to no effort to organize and document code