

## Compilers [Fall 2017]

### Programming Assignment V

#### Objectives

1. To learn basic typing rules (i.e., *static semantics*) for an object-oriented language with inheritance and subtyping.
2. To implement an enhanced symbol table for Diminished Java (DJ) programs.
3. To implement a type checker for DJ programs.

**Due Date:** Sunday, November 12, 2017 (at 11:59pm).

#### Machine Details

Complete this assignment by yourself on the following CSEE network computers: c4lab01, c4lab02, ..., c4lab20. These machines are physically located in ENB 220. You can connect to these machines from home using SSH. (Example: Host name: *c4lab01.csee.usf.edu* Login ID and Password: <your NetID username and password>) You are responsible for ensuring that your programs compile and execute properly on these machines.

#### Assignment Description

This assignment asks you to extend your dj2dism compiler with type checking (i.e., semantic analysis). The type checker will rely on symbol-table data structures.

Begin by downloading and studying the header files for the symbol-table module (in file *syntbl.h*) and the type-checking module (in file *typecheck.h*). These files are posted at <http://www.cse.usf.edu/~ligatti/compilers-17/as5>.

Implement the `typecheckProgram` method (declared in *typecheck.h*) in a new file called *typecheck.c*. For extra credit, you may also implement the `setupSymbolTables` method (declared in *syntbl.h*) in a new file called *syntbl.c*.

If you are completing this assignment by extending your Assignment IV implementation (as is recommended), you'll also have to make a few minor modifications to your *dj.y*:

1. The *syntbl.h* and *typecheck.h* header files need to be included.
2. The main method in *dj.y*, which is the main method of the entire compiler, needs to invoke `setupSymbolTables` and `typecheckProgram` so that the compiler actually performs the type checking.
3. Once you're confident that your compiler produces correct ASTs, you'll no longer want your compiler to print ASTs during normal operation (users generally don't want to see the ASTs their compilers build). Therefore, remove the call to `printAST` from *dj.y* (possibly, e.g., by setting a `DEBUG_PARSE` flag to 0).

#### Notes on Typing DJ Programs (beyond those given in the *Definition of DJ* handout):

- A list of expressions has the same type as the final expression in the list.
- A DJ method *M* may “redeclare” variable names locally or in its parameter that are already defined as class variables. In this case, the local/parameter declaration *punctures the scope* of the class variable, so any use of the variable in *M* refers to the

local/parameter rather than the class variable. However, a variable-expression block *B* may not redeclare variables that have already been declared in *B* (or that have the same name as a parameter that can be used in *B*).

- The expression `null` has type “any object”, which is a subtype of every class.
- The expression `new C()` has type *C*.
- An equality expression `E1==E2` is well typed (with type *nat*) exactly when (1) *E1* has valid type *T1*, (2) *E2* has valid type *T2*, and (3) either *T1* is a subtype of *T2* or *T2* is a subtype of *T1*.
- An if-then-else expression is well typed exactly when its if-expression has *nat* type and either (1) the then- and else-expression-lists both have *nat* type, or (2) the then- and else-expression-lists both have an object type. In case (1), the type of the entire if-then-else is *nat*. In case (2), the type of the entire if-then-else expression is the *join* of the types of the then- and else-expression-lists. For example, the expression `if(true) {null;} else{new Object();}` has type *Object* because the join of “any-object” type and *Object* is *Object*.
- A while-loop expression is well typed (with a *nat* type) exactly when its test expression has *nat* type and its body is well typed.
- A method that expects a parameter of type *C* may be passed any parameter that is a subtype of *C*.
- A method *M*, declared to return a value of type *T*, may return any value whose type is a subtype of *T*. In any case, the method’s return type is still considered to be its declared return type *T*.
- The assignment expression `ID=E` (where *ID* is an identifier and *E* is an expression) is well typed (with whatever type *ID* has) exactly when (1) *ID* is a well-typed variable and (2) *E*’s type is a subtype of *ID*’s type. Assignment expressions of the form `E.ID=E` are type checked similarly.
- A use of the keyword *this* must appear inside a declaration of some class *C*, in which case *this* has type *C*.
- The class hierarchy declared in a DJ program may not contain cycles (e.g., we cannot have *C1* a subclass of *C2*, *C2* a subclass of *C3*, and *C3* a subclass of *C1*). Similarly, no class may be its own superclass.
- Overriding methods’ parameter *names* may differ from those of overridden methods.
- The main block of a DJ program must be well typed (though it may have any type).
- Of course, all variables must be declared prior to use.

The examples at <http://www.cse.usf.edu/~ligatti/compilers-17/as1/dj/examples/bad/> are intended to illustrate all the high-level sorts of typing errors that are possible in DJ. Although more typing errors are possible, the additional possibilities should be simple variations of errors illustrated in the posted examples. (E.g., *bad19.dj* illustrates an error in which the second operand in a conjunction expression has non-*nat* type; obviously your type checker needs to ensure that both operands have *nat* type.)

## Hints

My *symb1.c* file is 273 lines of code (69 of which are comments/whitespace), while my *typecheck.c* file is 638 lines of code (65 of which are comments/whitespace; many others are checks that pointers about to be dereferenced are non-null). This is a relatively

challenging assignment, requiring you to write several hundred lines of code. Please budget your time accordingly.

Many examples of valid and invalid DJ files, on which you can test your type checker, are posted at <http://www.cse.usf.edu/~ligatti/compilers-17/as1/dj/examples>. A complete solution to this assignment will detect an error in every one of the “bad” example DJ programs and no errors in any of the “good” example DJ programs. As usual, we’ll grade your type checker on DJ programs that haven’t been distributed to the class.

## Grading

Your grade on this assignment is determined by the level to which you implement the desired functionality:

- *Level I:* `typecheckProgram` correctly type checks all DJ programs that (1) declare no classes and (2) declare no local variables (hence you never even need to use the symbol tables). Please note that at this level you can *only* assume that DJ programs input to your type checker declare no classes and no variables; input programs may still contain expressions with identifiers, the *new* keyword, the *null* keyword, etc. Expect to write about 250 lines of code for this level.
- *Level II:* `typecheckProgram` correctly type checks all DJ programs that declare no classes. For this level, expect to write about 50 lines of code beyond that of Level I.
- *Level III:* `typecheckProgram` correctly type checks all DJ programs (with the `typeExpr` function properly setting the `staticClassNum` and `staticMemberNum` AST-node attributes, which should be used in Assignment VI).

Undergraduate students will earn: 85% credit for reaching Level I, 100% credit for reaching Level II, and 110% credit for reaching Level III.

Graduate students will earn: 60% credit for reaching Level I, 75% credit for reaching Level II, and 100% credit for reaching Level III.

All students will earn +10% extra credit for correctly implementing the `setupSymbolTables` method in a file called `syntbl.c`.

## Compilation of the Type Checker

To compile your type checker from scratch, use the following sequence of commands.

```
> flex dj.l
> bison -v dj.y
> gcc dj.tab.c ast.c syntbl.c typecheck.c -o dj-tc
```

Alternatively, you can download a working version of the lexer and parser as object-code file `dj.tab.o` at <http://www.cse.usf.edu/~ligatti/compilers-17/as5>. Also at that URL you’ll find object-code files `ast.o` (the AST module) and `syntbl.o` (which can be used if you decide not to implement `syntbl.c`). These object-code files are executable on the C4 Linux machines.

If you’ve downloaded `dj.tab.o`, `ast.o`, and `syntbl.o` (in addition to the header files `ast.h`, `syntbl.h`, and `typecheck.h`), compile your type checker with:

```
> gcc dj.tab.o ast.o syntbl.o typecheck.c -o dj-tc
```

Please remember that it's recommended for you to try to build a full Level-III dj2dism compiler from scratch (i.e., without using any of the provided object-code files), and you'll receive extra credit on the final assignment for doing so.

### Example Executions

As with Assignments III and IV, your type checker should first report lexical and syntactic errors before exiting. Assuming there are no lexical or syntactic errors, your compiler performs type checking. If the input DJ program is well typed, your type checker should output nothing.

```
> ./dj-tc good1.dj
```

Otherwise, your type checker must report at least one error before exiting. *Errors must be reported with (1) reasonably accurate and helpful error messages and (2) the line numbers on which the errors occur.* For example:

```
> ./dj-tc bad3.dj
Semantic analysis error on line 7:
  Variable declared multiple times (here and in a superclass)
> ./dj-tc bad9.dj
Semantic analysis error on line 3:
  Invalid declared return type
> ./dj-tc bad14.dj
Semantic analysis error on line 9:
  non-nat type in printNat
> ./dj-tc bad44.dj
Semantic analysis error on line 6:
  reference to 'this' outside of a class
```

### Submission Notes

- Type the following pledge as an initial comment in your *typecheck.c* and (optional) *syntbl.c* files: “I pledge my Honor that I have not cheated, and will not cheat, on this assignment.” Type your name after the pledge. Not including this pledge will lower your grade 50%.
- Upload and submit your *typecheck.c* and (optional) *syntbl.c* files on Canvas. Upload and submit each file by itself; do not zip them into one.
- ***When submitting your code in Canvas, include with your submission a comment indicating at which level we should grade your assignment: I, II, or III. If you don't indicate a level, we'll grade your submission as a Level-III submission.***
- You may submit your assignment in Canvas as many times as you like; we'll grade your latest submission.
- For every day that your assignment is late (up to 3 days), your grade reduces 10%.
- To make it easier for our teaching assistant to read and evaluate your code, use spaces rather than tabs in your code and avoid long lines of code (I try to limit lines to 80 characters in width).
- Your programs will be graded on both correctness and style, so include good comments, well-chosen variable names, etc. in your programs.