Decaf Language Reference Manual

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February 12, 2012

`Decaf` is a small object oriented language with arrays, overloading, inheritance, and static method and field resolution. It is inspired by the Java$^{\text{TM}}$ programming language, and inherits many features of Java. This language was designed for use in Programming Languages and Compilers courses. It is small enough that a complete compiler/interpreter can be built for it in a single semester. Nevertheless, it has sufficiently rich set of features for writing a large set of object-oriented programs.

This manual outlines the syntax and semantics of the language constructs in `Decaf`. The syntax is described in Extended Backus-Naur Form (EBNF) notation. In EBNF, which combines regular-expression-like notation with grammars, x^* stands for a sequence of zero or more x's; x^+ stands for a sequence of one or more x's; $(x \mid y)$ stands for choice between x and y; and $x^?$ stands an optional occurrence (i.e., zero or one) of x. In the following, symbols in **bold face** represent reserved words and special characters: i.e., tokens with unique lexemes, such as **while**. Symbols in *italics* are either nonterminal grammar symbols, or terminal symbols with attributes, such as *int_const*.

1 Lexical Issues

`Decaf` is *case-sensitive*; for example, `for` and `For` are treated as distinct lexical entities.

White Space and Comments

Whitespace (blanks, newlines and tabs) serve to separate tokens; otherwise they are ignored. Whitespace may not appear within any token except a string constant (see below).

`Decaf` supports two styles of comments:

- Multi-line (C-style) comments that begin with "**/***" and end with "***/**". These comments may not be nested.

- Single-line comments that start with "**//**" and terminate at the end of line.

Comments may appear wherever a whitespace may appear.

Reserved words

The following are reserved words.

```
boolean    break    continue   class    do      else
extends    false    float      for      if      int
new        null     private    public   return  static
super      this     true       void     while
```

Constants

There are three types of constants supported by Decaf: integer, floating point and string constants.

Integer constants are made up of one or more digits, each digit ranging from 0 thru 9.

Floating point constants are of two kinds. Floating point constants of the first kind have of a decimal point ("."), and a sequence of one or more digits on either side of it (*e.g.*, `3.14159`). Floating point constants of the second kind have a *mantissa* and *exponent* separated by an exponent symbol, which is a lower-case or upper-case "e" (i.e. "`e`" or "`E`"). The mantissa is either an integer constant, or a floating point constant of the first kind. The exponent is an integer, optionally prefixed with a "+" or "-" sign. Examples of floating point constants of the second kind are: `1.61E-19`, `6.022E23`, `3.0E+8`, `2e32`, `3e+8`, and `2e-16`.

String constants begin and end with a double quote ("`"`"). If the string itself contains a double quote, it is "escaped" with a backslash (\) as in the example string: `"\"What?\" she exclaimed."`. Escape sequences, such as `\n` and `\t` are used to place special characters such as newlines and tabs in a string. If the string contains a backslash, that is escaped too (e.g., `"The computer simply responded with \"A:\\>\""`). Strings must be contained within a single line.

Decaf does not support character constants.

Integer, floating point and string constants are denoted in the syntax descriptions below, by *int_const*, *float_const* and *string_const* respectively.

Identifiers

Letters denote the upper and lower case elements of the English alphabet (`a` thru `z` and `A` thru `Z`).

An identifier is a sequence of letters, digits and underscore (_), starting with a letter, that is not one of the reserved words. Identifiers are denoted by the symbol *id*.

2 Declarations

A Decaf program is a sequence of **class** declarations.

   program   ::=   *class_decl**

Class Declarations

A **class** declaration associates a set of fields, methods and constructors to a class name. Its syntax is:

$$\begin{array}{rcl}
\textit{class\_decl} & ::= & \textbf{class } \textit{id } (\textbf{extends } \textit{id})^? \\
& & \qquad \{ \textit{ class\_body\_decl}^+ \; \} \\
\textit{class\_body\_decl} & ::= & \textit{field\_decl} \\
& | & \textit{method\_decl} \\
& | & \textit{constructor\_decl}
\end{array}$$

Each class declaration (e.g., **class foo ...**) creates a new class with the given name (e.g., **foo**). The **extends** option is used to specify a superclass, from which the current class inherits its fields and methods. *Field* declarations specify the fields that objects in this class will have; *method* declarations specify the methods that can be used on objects in this class; and *constructor* declarations are used to specify any initialization that needs to be done when a new object in this class is created.

Fields

The syntax of field declarations in `Decaf` is:

$$\begin{array}{rcl}
\textit{field\_decl} & ::= & \textit{modifier var\_decl} \\
\\
\textit{modifier} & ::= & (\textbf{public} \mid \textbf{private})^? \; (\textbf{static})^? \\
\\
\textit{var\_decl} & ::= & \textit{type variables } \textbf{;} \\
\\
\textit{type} & ::= & \textbf{int} \\
& | & \textbf{float} \\
& | & \textbf{boolean} \\
& | & \textit{id} \\
\\
\textit{variables} & ::= & \textit{variable } (\textbf{,} \textit{ variable})^* \\
\textit{variable} & ::= & \textit{id } (\textbf{[ ]})^*
\end{array}$$

Field declarations may be prefixed with modifiers as specified by the above syntax. A **public** field is a variable that can be accessed from methods defined in any other class. A **private** field is variable that can be accessed only from methods defined in the same class. If a field is not explicitly specified as private or public, it is assumed to be private.

Fields that are declared **static** are called *class variables*; fields that are not declared **static** are called *instance variables*. Each instance of a class gets its own private copy of all instance variables declared in the class. However, all instance of a class share a single copy of the class variables declared in the class.

A field may be one of the predefined types (**int**, **float**, **boolean**) or it may be an object in a user-defined class.

Multiple fields, all of same type, may be declared in a single statement; in this case, field names are separated by commas.

Array fields are defined by specifying [] after the field name. The number of []'s specify the number of dimensions of the array. Note that, as in Java, this only *declares* the array, and does not *create* one, i.e., allocate space for it. The array will be created, dynamically, using the **new** construct, described later in this manual.

Inheritance: All objects of a class c contain instance fields defined in c as well as instance fields defined in all superclasses of c. A class may contain a new field whose name is identical to one in

a superclass. However, only one field of a given name can be defined in a class, irrespective of the types.

Methods and Constructors

Methods in a class encapsulate procedures for manipulating objects belonging to a class. Constructors in a class are used to initialize objects of the class whenever they are created. The syntax of method and constructor declarations is as follows:

$$\begin{array}{rcl} method\_decl & ::= & modifier \ (type \ | \ \textbf{void}) \ id \ (\ formals^? \ ) \ block \\[2mm] constructor\_decl & ::= & modifier \ id \ (\ formals^? \ ) \ block \\[2mm] formals & ::= & formal\_param \ (, \ formal\_param)^* \\ formal\_param & ::= & type \ variable \end{array}$$

The **public** and **private** modifiers are used to specify whether the given method can be accessed from methods in other classes. Methods declared **static** are called *class methods* and those not declared **static** are called *instance methods*. Instance methods always operate on a specific instance of the class, whereas class methods operate on the class as a whole and not on individual instances. A method that returns nothing (i.e., a procedure) has a return type of **void**. Methods may take a list of arguments, the name and type of which are given by a list of formal parameters.

There may be multiple methods of the same name defined within a class, as long as they can be distinguished on the basis of the number or types of parameters.

The name of a constructor must be same as that of the parent class. Constructors may also take a list of arguments, again specified as by the list of formal parameters.

The body of a method or constructor is specified by a *block* of statements, described below.

3   Statements

`Decaf` supports a small but expressive set of control primitives to specify procedures for manipulating the objects.

The syntax of `Decaf` statements is:

$$\begin{array}{rcl} block & ::= & \textbf{\{ } stmt^* \textbf{ \}} \\[2mm] stmt & ::= & \textbf{if (} \ expr \ \textbf{)} \ stmt \ (\textbf{else} \ stmt)^? \\ & | & \textbf{while (} \ expr \ \textbf{)} \ stmt \\ & | & \textbf{for (} \ stmt\_expr^? \ \textbf{;} \ expr^? \ \textbf{;} \ stmt\_expr^? \ \textbf{)} \ stmt \\ & | & \textbf{return} \ expr^? \ \textbf{;} \\ & | & stmt\_expr \ \textbf{;} \\ & | & \textbf{break ;} \\ & | & \textbf{continue ;} \\ & | & block \\ & | & var\_decl \\ & | & \textbf{;} \end{array}$$

A block of statements is comprised of a (possibly empty) set of declarations for variables local to that block, followed by a sequence of statements.

If statement: An if-statement of the form **if (** *expr* **)** *stmt* evaluates the boolean expression *expr*; if the expression evaluates to **true**, then the statement *stmt* is executed. When the optional

else part is present, of the form **else** *stmt'*, then the statement *stmt'* is executed if the expression evaluates to **false**.

While statement: A while-statement of the form **while (** *expr* **) stmt** loops, evaluating *expr* first and executing *stmt* as long as *expr* is true. The loop is exited when *expr* evaluates to **false**.

For statement: A for-statement of the form **for (** s_1 **;** e_2 **;** s_3 **)** $stmt_4$ has four components: an initializer s_1, which is evaluated on entry to the statement; the boolean expression e_2, which is evaluated at the beginning of each iteration through the loop; an update part s_3, which is executed at the end of each iteration through the loop; and statement $stmt_4$, which is executed as long as e_2 evaluates to **true**. The loop is exited when e_2 evaluates to **false**.

Return statement: A return statement signifies the end of control in a method. The expression *expr* is evaluated and is returned to the caller of the method. Thus the declared return type of the method must be compatible with the type of *expr*. If the return type of the method is **void**, then the *expr* part of the return statement is omitted.

Expression statement: Certain expressions, such as assignments and post-increment operations, denoted by *stmt_expr*, can be stand-alone statements. See Section 4 for syntax of *stmt_expr*.

Block statement: A block of statements can themselves be used wherever a statement is used. When a block statement is executed, the local variables declared in that block are freshly created, and the sequence of statements in that block are executed in order.

Empty statement: An empty statement is specified simply by ';'. It has no effect on execution.

4   Expressions

Objects and their values are manipluated using a variety of expressions. The simplest form of expressions are literal constants:

literal	::=	*int_const*
	|	*float_const*
	|	*string_const*
	|	**null**
	|	**true**
	|	**false**

In the following, the nonterminal grammar symbol *expr* is used to denote the set of all expressions allowed in `Decaf`. Literal constants, creation of new instances of objects, access of object fields and arrays, and method invocation are among the basic set of expressions used in `Decaf`, called *primary* expressions, the syntax of which is given below:

$$
\begin{array}{rcl}
primary & ::= & literal \\
 & | & \textbf{this} \\
 & | & \textbf{super} \\
 & | & \textbf{(}\ expr\ \textbf{)} \\
 & | & \textbf{new}\ id\ \textbf{(}\ arguments^{?}\ \textbf{)} \\
 & | & lhs \\
 & | & method\_invocation \\
\\
arguments & ::= & expr\ \textbf{(}\ \textbf{,}\ expr\ \textbf{)}^{*} \\
\\
lhs & ::= & field\_access \\
 & | & array\_access \\
\\
field\_access & ::= & primary\ \textbf{.}\ id \\
 & | & id \\
\\
array\_access & ::= & primary\ \textbf{[}\ expr\ \textbf{]} \\
\\
method\_invocation & ::= & field\_access\ \textbf{(}\ arguments^{?}\ \textbf{)}
\end{array}
$$

The reserved word **this** is used to represent the current object, i.e., the object on which the method containing the current expression is applied. The reserved word **super** is used to explicitly access fields or methods in the superclass; this construct is primarily used when names alone are insufficient to distinguish fields and methods in a class from those of its superclass.

A new object is created using the reserved word **new**. The arguments supplied with the name of the class correspond to parameters of the constructor to be used to initialize the new object.

An *lhs* expression is an expression that can occur on the left hand side of an assignment: either referring to a field of an object, or to an element of an array.

A field in an object of class c can be accessed by simply using the name of the field, provided it is being accessed from a method defined in class c. If there are multiple objects of class c, or if the field is accessed from a method defined in a different class, the field is specified using the notation "*object.field*". A method invocation takes the form "*object.method(args)*". If a method invocation does not explicitly specify an object, then **this** is assumed as the default object.

The syntax of array access resembles that of array accesses in C: *array*[*index*]. Multidimensional arrays are accessed by specifying a sequence of indices, each index enclosed in square brackets. An array is assumed to be created before it is accessed.

Other expressions in `Decaf` are defined using the primary expressions described above.

$$
\begin{array}{rcl}
expr & ::= & primary \\
 & | & assign \\
 & | & new\_array \\
 & | & expr\ arith\_op\ expr \\
 & | & expr\ bool\_op\ expr \\
 & | & unary\_op\ expr \\[4pt]
assign & ::= & lhs\ =\ expr \\
 & | & lhs\ \text{++} \\
 & | & \text{++}\ lhs \\
 & | & lhs\ \text{--} \\
 & | & \text{--}\ lhs \\[4pt]
new\_array & ::= & \textbf{new}\ type\ (\text{[}\ expr\ \text{]})^{+}\ (\text{[ ]})^{*} \\[4pt]
arith\_op & \in & \{ +, -, *, / \} \\[4pt]
bool\_op & \in & \{\ \&\&, ||, ==, !=, <, >, <=, >=\ \} \\[4pt]
unary\_op & \in & \{ +, -, ! \}
\end{array}
$$

An assignment expression can be an explicit assignment, specified using the assignment operator $=$, or an implicit assignment, specified by the pre- or post- increment ($++$) or decrement ($--$) operators. An array is created with the **new** operator by specifying the type of array and the sizes along its different dimensions. The sizes are, in general, integer expressions (not just integer constants).

`Decaf` provides a set of commonly used arithmetic and relational operators. Binary arithmetic operators include addition ($+$), subtraction ($-$), multiplication ($*$) and division ($/$), which operate on integers or floating point numbers. Boolean operators include:

- equality and disequality operations ($==$, $!=$) that can be applied, in addition to integer and floating point expressions, to objects of any type, as long as both objects being compared are of the same type;

- common relational operations ($>, <, >=$ and $<=$) on integer and floating point expressions; and

- logical operations conjunction ($\&\&$) and disjunction ($||$).

Unary operators include unary plus ($+$), minus ($-$) that operates on integer and floating point expressions and negation ($!$) that operates on boolean expressions.

The explicit assignment ($=$) associates to the right. Relational operators ($>, <, >=$ and $<=$) are nonassociative. All other binary operators associate to the left. Hence, the expression $a + b + c + d$ is treated as $((a + b) + c) + d$, while the expression $a = b = c = d$ is treated as $a = (b = (c = d))$. The precedence of the operators is defined in Table 1 which lists the operators from highest to lowest precedence.

Finally, statement expressions are those, such as assignments and method invocations, that can occur as stand-alone statements. Their syntax is defined by the following rule:

$$
\begin{array}{rcl}
stmt\_expr & ::= & assign \\
 & | & method\_invocation
\end{array}
$$

highest precedence	!
	*, /
	+, −
	<, >, <=, >=
	==, !=
	&&
	||
lowest precedence	=

Table 1: Precedence of binary operators in `Decaf`

5 Standard Objects and Methods

`Decaf` provides two standard objects: `Out` which represents the standard output file (the console) and `In` which represents the standard input file (the keyboard). The methods that can be used on these objects are:

1. `print(`*expr*`)`: This is an overloaded method, which can take objects of any primitive type (integers, floating point numbers and booleans) as well as string constants, and writes their values to the given file.

   The method is usually applied to `Out` and returns void.

2. `scan_int()`: This method, usually applied to `In`, reads a stream of characters from file that represent an integer and returns the corresponding integer value.

3. `scan_float()`: Similar to `scan_int()`, this method is used to read a floating point value from the given file.

Entry Point

A class whose name is same as the filename of the program is the "main" object of the program. For instance, if the program is in file `foo.decaf`, then class `foo` is the main class in the program. A static, public, parameterless method called `main` in class `foo` is the entry point of the program in `foo.decaf`. That is, when invoked from the command line, `main()` will be the first method invoked from the operating system.

6 Sample `Decaf` Programs

Following are four sample programs of varying complexity written in `Decaf`.

hello_world.decaf
This program prints `"Hello World!"` on the console and exits.

```
class hello_world{
      public static void main() {
              Out.print("Hello World!\n");
      }
}
```

nrfib.decaf
The following program computes and prints the nth Fibonacci number, given n as the input. The Fibonacci number is computed using a nonrecursive procedure.

```
class nrfib{
      public static void main() {
              int n, i, fn, fn_prev;

              n = In.scan_int();

              fn = 1;
              fn_1 = 0;

              for(i=1; i<n; i=i+1) {
                      fn = fn_prev + fn;
                      fn_prev = fn - fn_prev;
              }
              Out.print("Fib = ");
              Out.print(fn);
              Out.print("\n");
      }
}
```

The following program computes and prints the nth Fibonacci number, given n as the input. The Fibonacci number is computed using a *recursive* procedure.

```
class rfib{
        static int fib(int n) {
                if (n <= 2)
                        return 1;
                else
                        return fib(n-1) + fib(n-2);
        }

        public static void main() {
                int n;

                n = In.scan_int();

                Out.print("Fib = ");
                Out.print(fib(n));
                Out.print("\n");
        }
}
```

IntList.decaf

This program implements an abstract datatype of (singly-linked) list with integer elements, with operations of insertion, search and length.

```
class IntList{
  int value;
  IntList next;

  public static IntList create_list(int v) {
    IntList new_element;

    new_element = new IntList();
    new_element.value = v;
    new_element.next = null;
    return new_element;
  }

  public IntList insert(int v) {
    IntList new_element;

    new_element = create_list(v);
    new_element.next = this;

    return new_element;
  }

  public boolean search(int v) {
    if (this.value == v)
      { /* head of list matches */
        return true;
      }
    else
      /* not at head, so search rest of list */
      if (next == null)
        { /* end of list, so search fails */
          return false;
        }
      else
        /* search rest of the list */
        return next.search(v);
  }

  public int length() {
    if (next == null)  return 1;
      else  return 1 + next.length();
  }
}
```

Acknowledgements