CS164: Midterm Exam 2

Fall 2004

- Please read all instructions (including these) carefully. **Write your name, login, and circle the time of your section.**
- Read each question carefully and think about what's being asked. Ask the proctor if you don't understand anything about any of the questions. **If you make any non-trivial assumptions, state them clearly.**
- You will have 1 hours and 20 minutes to work on the exam. The exam is closed book, but you may refer to your one page of handwritten notes.
- Solutions will be graded on correctness and **clarity,** so make sure your answers are neat and coherent. Remember that if we can't read it, it's wrong!
- Each question has a relatively simple and straightforward solution. **We will deduct points if your solution is far more complicated than necessary.** Partial answers will be graded for partial credit.
- Turn off your cell phone.
- Good luck!

NAME and LOGIN: ____

Your SSN or Student ID: ________________________

Circle the time of your section: 10:00 11:00 2:00 4:00

Q1 (50 points)	Q2 (50 points)	Total (**100** points)

1 Dataflow analysis

This question asks you to develop a simple dataflow analysis that can be used to optimize Decaf programs be removing from them unnecessary null checks.

Background. Because dereferencing a `null` pointer crashes the program, in Decaf, a run-time check ensures that a `null` pointer is never dereferenced. This check takes place just before the pointer is dereferenced using the "." operator. For example, the statement "`p.f();` " might be translated by the compiler to

```
if (p == null) print_error_and_exit{);
p.f 0 ;
```

The null checks can be costly, but luckily we can optimize some of them away. Specifically, a check can be safely removed if the compiler can guarantee that the pointer being dereferenced will not be null for any program input.

The problem. In this problem, you will develop a dataflow analysis to identify such redundant checks, so that they can be eliminated by the compiler. In particular, for every pointer dereference, you want to know whether the variable being dereferenced may be null; if it may not, then you can eliminate the null check.

Simplifications. In order to simplify the analysis, you can make the following assumptions:

- Assume that the method that you are going to analyze has only three local variables named `x, y, z.`
- These variables are initialized to `null .`
- All three variables are of type `B`, where `B` is a class defined as follows
  ```
  class B {
    void foo();
    B moo();
  }
  ```
- The return value of `moo` can be either a `null` pointer or a valid pointer.
- Within a basic block, the only valid statements are an assignment into a local variable and a method call (like `z.foo();`).
- The right hand side of an assignment can be any of the following:
  - A method call (like `z.moo()`),
  - `new B()`,
  - Another variable,
  - `null`.

The questions.

1. (4 points) Give a program with 3 statements or less where the null-check is unnecessary, and explain why it is unnecessary. (Make sure your example uses only the language constructs listed on the previous page.)

2. (4 points) Dataflow analysis can be classified as either forward or backward. Is your analysis going to forward or backward? Explain why.

3. (5 points) As mentioned earlier, your goal is to find, for all pointer dereference expressions, whether the pointer may be null. Give the values that the analysis will use to represent the fact that the pointer is (is not) null. Give the meaning of these values. (Hint: recall that in Liveness analysis we used two such values for each variable: "x is live" and "x is not live". Recall how we defined their meaning.)

4. (3 points) What is the ordering of these two values (for now, assume that you are analyzing each variable independently).

5. (4 points) Assume now that you want to do the analysis for all three variables simultaneously. With this in mind, define the lattice you will use for the dataflow analysis (i.e. show the values that you are going to be assigning to program points, and the ordering you are going to impose on them).

6. (12 points) If you are using a forward analysis, specify for each of the following statements how the value at program point B is computed given the value at the program point A (i.e. how do you decide what variables may be null at B given what you know about the variables at A).

If you are using a backward analysis, specify how you are going to compute the value at program point A from the value at program point B.

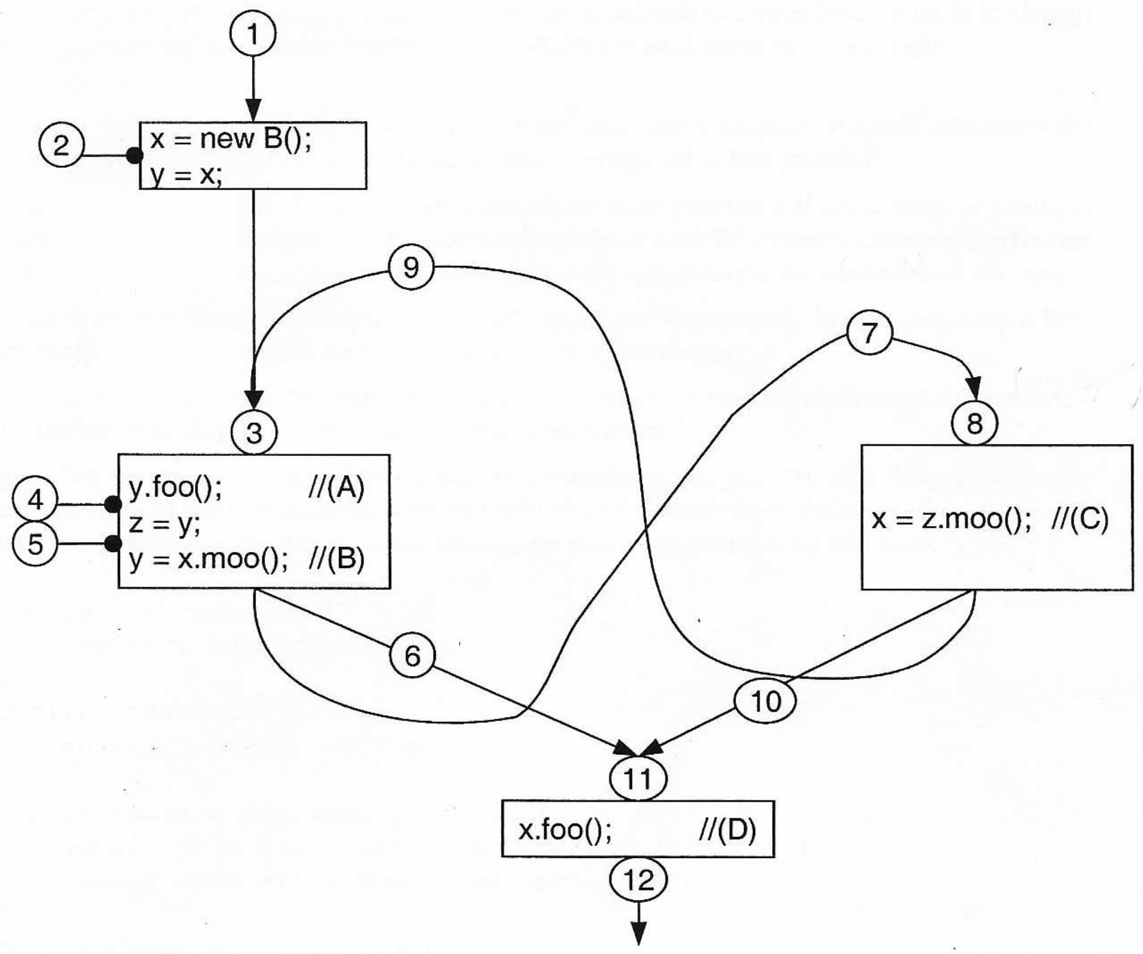
Your analysis should not be overly conservative. ~~You can assume you are analyzing each variable separately~~

(A) `x = null;` (B)	(A) `X = new B();` (B)	(A) `x = y;` (B)	(A) `x = y.moo();` (B) (hint: If y were null, you would never reach point (B))

7. (4 points) How are you going to handle join points (or split points if you are doing a backward analysis)? In particular, if you have two different values coming into a join point from two different edges, how are you going to define the value for the join point?

8. (4 points) What value are you going to initialize all program points too? What about the entry point (or the exit point if you are running a backward analysis)?

9. (10 points) Run your data-flow analysis on the graph given below, and fill out the two tables provided.



Program point	Analysis value
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

Pointer Dereference	safe to remove the check? (Yes/No)
(A)	
(B)	
(C)	
(D)	

2 Run-time Organization for Interfaces

This question asks you to extend Decaf with Java-style interfaces. Your main goal is to design dispatch tables needed to support interface calls, which are analogous to virtual calls.

Background. If you are not familiar with Java interfaces, don't despair. We will introduce the running example with sufficient background so that you can solve this problem.

First, you need to know that the goal of Java interfaces is to provide a limited form of multiple inheritance. This is how multiple inheritance works in Java: each Java class `extends` exactly one class and `implements` zero or more interfaces. (The only exception is the special class `Object`.)

Now, what is an interface? For the purpose of this question (we simplify Java somewhat), a Java interface is simply a class whose members are all abstract methods.

Also, what does it mean to implement an interface? A class *C* is said to implement an interface *I* when *C* implements (that is, defines bodies of) all methods of *I*

Example. The simple example below defines two interfaces (IK and IM) and three classes that implement (some) of the two interfaces. Notice that class C doesn't itself define method m, yet it is considered to implement the interface IM. Make sure you understand why this is so.

```
public interface IK {
    abstract public void k();
}
public interface IM {
    abstract public void m();
}
public class A implements IK, IM {
    public void k() { System.out.println("A:k"); }
    public void m() { System.out.println("A:m"); }
}
public class B implements IK {
    public void k() { System.out.println("B:k"); }
    public void m() { System.out.println("B:m"); }
}
public class C extends B implements IM {
    public void k() { System.out.println("C:k"); }
}
```

Interface references. To make use of interfaces, Java introduces *interface reference* variables, which are like object reference variables, except that an interface variable of type *I* is allowed to point to objects of *any* type *T* such that the class *T* implements the interface *I*. For example, the interface reference variable `t` of type `IM` (introduced above) is allowed to point to an object of type `A` or `C` but not of type `B`, even though `B` happens to contain a method `m()`:

```
IM t;
t = new A();   // LEGAL
t = new B();   // ILLEGAL (even though B contains method m)
t = new C();   // LEGAL

t.m();          // LEGAL
t.k();          // ILLEGAL (even though t is guaranteed to point
                //           to an object with method k)
```

Compiling interfaces. Compiling Java interfaces boils down to supporting a new kind of method call `t.m()`, named *interface method call.* To the programmer, this call behaves like the *virtual method call* used to invoke instance methods, except that the object on which you invoke the method m comes from an interface reference variable `t`, as opposed to from an object reference variable.

Example (continued). The code below makes both kinds of calls.

```
B b; // b can point to any object of type B or subclass of B
IK ik; // ik can point to any object that implements interface IK

if (x==l) {
    b = new B();
    ik = new A();
} else {
    b = new C();
    ik = new C();
}
b.k();  // virtual call
ik.k(); // interface call
```

When `x==1`, the program outputs

```
B:k
A:k
```

Turn over.

The questions.

1. (3 points) What output does the example print when `x!=1`?

2. (3 points) In the table below, indicate for each class which interfaces it implements. Note that a class is considered to implement an interface if its superclass implements the interface. It may help if you draw the class hierarchy in which you show with edges which class implements which interfaces.

class	A	B	C
implemented interfaces			

3. (3 point) In the table below, indicate which methods can be invoked on a reference variable of a particular static type. For example, list method m in column *A* if the following code is legal:
`A a; ...; a.m();`

static type	A	B	C	IK	IM
methods that can be invoked					

4. (3 point) What types of objects can `b` and `ik` point to at run time?

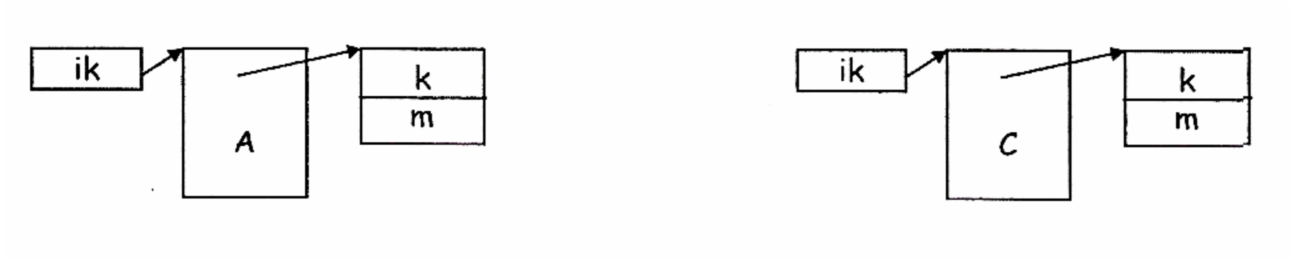
call statement	`b.k()` virtual call	`ik.k()` interface call
dynamic types of the object		

5. (4 point) Looking at the immediately preceding table, what is the property that the types of the virtual call have that the types of the interface call don't?

6. (6 points) The figures below show the (traditional) dispatch tables for two executions of the example (left: *x* = 1; right: *x* != 1). These dispatch tables are used in virtual calls. From these two figures, it appears that virtual dispatch tables can be used to correctly implement interface calls. However, this impression is incorrect.

To show why virtual dispatch tables are insufficient, modify our running example (given on pages 6 and 7) so that the dispatch tables don't work in interface calls. Write your modification in the blank space below.

To reflect your modification to the example, modify also the dispatch tables shown below.



7. (4 points) Explain (concisely) the reason why interface method calls cannot rely on the traditional dispatch tables to decide which method to invoke.

Questions on this page will take you some time.

8. (14 points) Design run-time support for interface calls. Note that the new run-time support need not look like a dispatch table at all.

What you need to draw: Using the running example above, show the data structures that your compiler would generate to perform the dispatch at an interface call.

Note: To earn full credit, the space requirements of your run-time data structures must not be a function of the number of interfaces in the entire program, only a function of how many interfaces a class implements.

Simplifications. (1) Assume interfaces cannot extend each other (as they can in Java). (2) Assume the program is completely available prior to the execution, as in Decaf (in contrast, in Java, classes are loaded and compiled during the execution).

9. (5 points) If your solution stores pointers (to methods or tables) in an array, give your rules for determining the index in the array where the pointer will be stored.

(An example of a rule: in the case of "traditional" virtual dispatch tables, the rule is that the pointer to a method `f` is (a) placed at the same offset in the dispatch tables of all classes related by inheritance; and (b) the methods of a subclass are placed immediately below the offset of the superclass.)

10. (5 points) Show the code that your compiler would generate at an interface call. Use a pseudo-code, not an assembler. Your code should assume the run-time data structures you designed above.