CIS 120 Final Exam December 16, 2013

Name (printed): ____________________________

Pennkey (e.g., bcpierce): ____________________________

My signature below certifies that I have complied with the University of Pennsylvania's Code of Academic Integrity in completing this examination.

Signature: ______________________________________ Date: _________________________

1	/10
2	/20
3	/12
4	/16
5	/11
6	/13
7	/14
8	/16
9	/8
Total	/120

- Do not begin the exam until invited to do so.
- You have 120 minutes to complete the exam. There are 120 total points possible. There are 18 pages in the exam, plus a 5-page appendix.
- Make sure your name and Pennkey (i.e., your login username) is on the top of this page.
- Be sure to allow enough time for all the problems—skim the entire exam first to get a sense of what there is to do.
- If you finish during the last 15 minutes of the exam time, please stay in your seat so as not to disturb others. If you finish before 15 minutes from the end, feel free to leave early.

1. True or False (10 points)

a. T F In OCaml, the binding between a variable and its value can never be changed.

b. T F In OCaml, if `x` is a variable of any type, `Some x == Some x` will always return **`true`**.

c. T F In Java, it is good practice, when overriding the `equals` method from `Object`, to override the `hashCode` method as well.

d. T F In Java, the default implementation of equality in the `Object` class uses reference equality for mutable objects and structural equality for immutable objects.

e. T F Java's *subtype polymorphism* is very similar to OCaml's *parametric polymorphism*, whereas Java's *generics* are a different thing with no direct analog in OCaml.

f. T F In Java, the dynamic class of the result of an expression will always be the same as or a subtype of its static type, even if casts are used.

g. T F In a Java `try-catch-finally` statement, the `finally` clause is executed only if the `try` clause does not throw an exception.

h. T F In Java, a `final` instance variable can only be changed in a constructor.

i. T F In Java, every method must declare in its header every exception it might throw.

j. T F In Java, if type `A` is a subtype of `B`, then `Set<A>` is a subtype of `Set<B>`.

2. **Array processing** (20 points)

In this problem you will implement a static method called `isPermutation` that takes as input two arrays of integers and returns true if the second array is a *permutation* of the first — i.e., the two arrays contain exactly the same elements, though perhaps in different orders. For example, if

```
int[] a = { 1, 2, 3, 3, 3 };
int[] b = { 3, 1, 3, 2, 3 };
int[] c = { 1, 2, 3 };
int[] d = { 1, 2, 3, 4, 5 };
int[] e = { 1, 1, 1, 2, 3 };
```

then `isPermutation` should return **`true`** when called on `a` and `b` and **`false`** when called on any other pair.

Getting this exactly right is a bit trickier than it might seem at first. One way to approach it is to notice that, if the arrays have the same length, then one is a permutation of the other if and only if each distinct element appears the same number of times in both. Remember to do something reasonable on null inputs. Do not use any external libraries such as collection classes.

```
class Main {
  public static boolean isPermutation(int[] x, int[] y) {









  }
}
```

3. Java ASM (12 points)

On page 4 of the appendix there are some object definitions and a `main` method refering to those.

For the `String` objects, you do not need to draw the class table part. Follow the pattern of the appendix in showing the `String` objects in the heap.

Draw the Java ASM (including the stack, heap, and class table) at the point of the computation marked */* Here */*. Do not write out the code in the method bodies: just show the headers for the methods belonging to each class in the class table.

4. OCaml Objects (16 points)

This question also uses the definitions on page 4 of the appendix.

We can encode `Animal` objects as values belonging to an OCaml record type with two fields, `speak` and `setSound`, corresponding to the methods of the same name above.

```
type animal = { speak : unit -> string;
                setSound : string -> unit }
```

Your task in this problem is to implement a "constructor" for such objects—i.e., a function `create` that builds values belonging to this record type. For example, the result of evaluating the following program should be `"duck says QUACK!"`

```
let duck = create "duck" "quack" in
duck.setSound "QUACK!";
duck.speak ()
```

Complete the definition of `create` below to achieve this behavior. Recall that the string concatenation operator in OCaml is written `^`.

```
let create (name : string) (sound : string) : animal =
```

5. Java Types and Exceptions (11 points)

Consider the following code, inspired by Homework 9:

```
public abstract class Corrector {
  public abstract Set<String> getCorrections(String wrong);
}

public class SpeelingCorrector extends Corrector {
  public Set<String> getCorrections(String wrong) {
    if (wrong.equals("speeling")) {
      Set<String> results = new HashSet<String>();
      results.add("spelling");
      return results;
    }
    return null;
  }
}
```

a. What is the static type of `results`?

b. What is the dynamic class of `results`?

c. Can the above code ever produce an exception? If so, which one?

d. Now consider the following `main` method refering to the definitions above.

```
public static void main(String[] args) {
  Corrector c = new Corrector();
  Set<String> corrections = c.getCorrections("speeling");
}
```

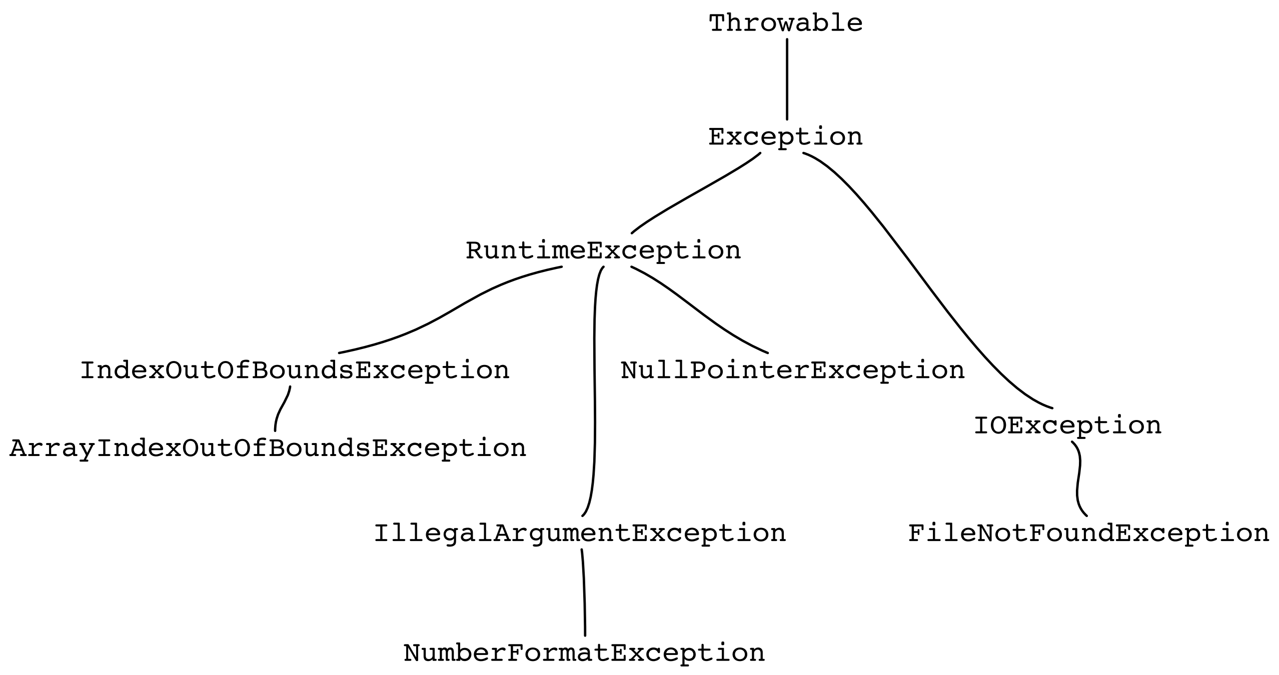
Will this method compile correctly? If not, why not? If yes, what is the value of `corrections` at the end of the execution?

e. Finally, consider a different `main` method:

```
public static void main(String[] args) {
  Reader r = new FileReader(args[0]);
  char c = (char) r.read();
  SpeelingCorrector s = new SpeelingCorrector();
  Set<String> corrections = s.getCorrections(String.valueOf(c));
}
```

Below, we've drawn a fragment of the exception hierarchy of Java.

Circle the exceptions that can be thrown during the execution of the above piece of code. (Do *not* circle supertypes of the exceptions that can be thrown, unless they are also thrown themselves.) You may find some useful information on page 2 of the appendix.



6. Collections and Equality (13 points)

a. The following comment is adapted from the Java library implementation of the `equals` method for both the `LinkedList` and `ArrayList` classes. (The details of how `ArrayList` and `LinkedList` work and how they differ from each other are not important for this problem. Everything you need to know is contained in the italicized text.)

```
public boolean equals(Object o)
```

Compares the specified object with this list for equality. Returns true if and only if the specified object is also a list, both lists have the same size, and all corresponding pairs of elements in the two lists are equal. (Two elements `e1` *and* `e2` *are equal if either both are* `null` *or else* `e1.equals(e2))`*.) In other words, two lists are defined to be equal if they contain the same elements in the same order.*

This implementation first checks if the specified object is exactly this list. If so, it returns true; if not, it checks if the specified object is a list. If not, it returns false; if so, it iterates over both lists, comparing corresponding pairs of elements (using `e`*quals). If any comparison returns false, this method returns false. If either iterator runs out of elements before the other it returns false (as the lists are of unequal length); otherwise it returns true when the iterations complete.*

Note that both `LinkedList` and `ArrayList` are subtypes of `List`.

Consider the following piece of code that creates some linked lists and arraylists:

```
String str = "CIS 120";

List<String> l1 = new LinkedList<String>();
l1.add(str);

List<String> l2 = new ArrayList<String>();
l2.add(str);

List<String> l3 = l1;
```

For each of the comparisons below, circle whether it returns **`true`** or returns **`false`**.

i. `l1.equals(l2)`

`true` **`false`**

ii. `l1 == l2`

`true` **`false`**

iii. `l1.equals(l3)`

`true` **`false`**

iv. `l1 == l3`

`true` **`false`**

v. `l2.equals(l3)`

`true` **`false`**

vi. `l2 == l3`

`true` **`false`**

b. Consider the following fragment of a `main` method, referring to a `Pair` class. Three possible implementations of `Pair` are given below.

```
// somewhere in main ...
Pair p = new Pair(1,2);
System.out.println(p.equals(new Pair(1,2)));
System.out.println(p.equals((Object) new Pair(1,2)));
```

For each of the following implementations of the `Pair` class, write down what is printed to the console when we call `main`.

i.
```
public class Pair {
  private final int x;
  private final int y;
  public Pair (int x, int y) { this.x = x; this.y = y; }
  public int getX() { return x; }
  public int getY() { return y; }
}
```

Answer:

ii.
```
public class Pair {
  // Same declarations and methods as (i)
  ...
  // plus this:
  public boolean equals(Pair that) {
    return (this.getX() == that.getX() &&
            this.getY() == that.getY());
}
```

Answer:

iii.
```
public class Pair {
  // Same declarations and methods as (i)
  ...
  // plus this:
  @Override
  public boolean equals(Object o) {
    boolean result = false;
    if (o instanceof Pair) {
      Pair that = (Pair) o;
      result = (this.getX() == that.getX() &&
                this.getY() == that.getY());
    }
    return result;
  }
}
```

Answer:

7. **Binary Trees** (14 points)

Recall the type definitions for binary trees from homework 2:

```
type 'a tree =
  | Empty
  | Node of 'a tree * 'a * 'a tree
```

Also recall that binary search trees (BST) are trees with an additional invariant (which hopefully you remember), and recall the `insert` function for BSTs:

```
let rec insert (x:'a) (t:'a tree) : 'a tree =
  begin match t with
    | Empty -> Node(Empty,x,Empty)
    | Node(lt,y,rt) ->
       if x = y
       then t
       else if x < y
       then Node(insert x lt,y,rt)
       else Node(lt,y, insert x rt)
  end
```

a. Which of the following OCaml values of type `tree` are valid BSTs? (Write "Yes" or "No" by each one.)

i. `let t1 : tree = Empty`

ii. `let t2 : tree = Node (Empty, 42, Empty)`

iii. `let t3 : tree = Node (insert 42 Empty, 41, Empty)`

iv. `let t4 : tree = insert 42 (Node (Empty, 41, Empty))`

v. `let t5 : tree = Node (Node (Empty, 42, Empty), 42, Empty)`

b. Also consider the following `insert_list` function using the `fold` higher order function. For your convenience, the definition of `fold` is in the appendix on page 3.

```
let insert_list (l : 'a list) (t : 'a tree) : 'a tree =
  fold insert t l
```

For each of the following code snippets, draw the resulting tree. Here is an example of a drawn tree:

```
  2
 / \
3   4
   / \
  5   6
```

i. `insert_list [1;2;3;4;5] Empty`

ii. `Node(insert_list [1;2] Empty, 42, insert_list [42; 120] Empty)`

iii. `insert_list [4;8;4;3;5;23;42] (insert_list [42] Empty)`

8. Ocaml Programming and Higher Order Functions (16 points)

In this problem you will be guided through the steps of coding a function `replicate`, which repeats all the elements of a list some given number of times.

a. Write a recursive function `repeat` that, given a number `n` and a value `x`, returns a list consisting of the value `x` repeated `n` times. Assume `n` is non-negative.

For example,

```
repeat 3 1 = [1; 1; 1]
repeat 2 'a' = ['a'; 'a']
repeat 0 "cis 120" = []
```

```
let rec repeat (n : int) (a : 'a) : 'a list =
```

b. Write a function `flat_transform` that, given a list `[a1;a2;...;an]` and a function `f`, produces the list `f a1 @ f a2 @ ... @ f an`. For example,

```
flat_transform (fun x -> [x; x+1]) [1;2] = [1;2;2;3]
```

Your solution must use a single call to one of the higher-order functions provided on page 3 of the appendix.

```
let flat_transform (f : 'a -> 'b list) (l : 'a list) : 'b list =
```

c. Use functions defined in parts (a) and (b) to write a function `replicate` that takes a non-negative number `n` and a list `l` and returns a new list where each element is repeated `n` times. For example:

```
replicate 2 [1;2;3] = [1;1;2;2;3;3]
```

Hint: You do not need any higher-order functions or recursion here. A simple combination of the functions you have coded above is enough!

```
let replicate (n : int) (l : 'a list) : 'a list =
```

9. **Design Process** (8 points)

List the four steps of the "design process" (or "recipe") that we used throughout the semester.

a.

b.

c.

d.

Reference Appendix

Make sure all of your answers are written in your exam booklet. These pages are provided for your reference—we will *not* grade any answers written in this section.

java.lang

```
public class String
  public String(char[] value)
   // Allocates a new String so that it represents the sequence of
   // characters currently contained in the array argument
  public char charAt(int index)
   // Returns the char value at the specified index
  public int length()
   // Returns the length of this string
  public boolean equals(Object anObject)
   // Compares this string to the specified object. The result is true if and
   // only if the argument is not null and is a String object that represents
   // the same sequence of characters as this object.
   public static String valueOf(char c)
   // Returns the string representation of the char argument.

public class Character
  public static boolean isWhiteSpace(char ch)
     // Determines if the specified character is whitespace
```

java.util (Collections Framework)

```
public interface Iterator<E>
   public boolean hasNext()
      // Returns true if the iteration has more elements. (In other words,
      // returns true if next would return an element rather than throwing an exception.)

   public E next()
      // Returns the next element in the iteration.
      // Throws: NoSuchElementException – iteration has no more elements.
```

java.io

```
public abstract class Reader
  public int read() throws IOException
    // Reads a single character. This method will block until a character
    //   is available, an I/O error occurs, or the end of the stream is reached.
    // Returns: The character read, as an integer in the range 0 to
    //    65535 (0x00-0xffff, or -1 if the end of the stream has been reached
    // Throws: IOException - If an I/O error occurs

public class BufferedReader extends Reader
  public BufferedReader(Reader in)
     // Creates a buffering character-input stream that uses a default-sized input buffer.
     // Parameters: in - A Reader

public class InputStreamReader extends Reader
  public InputStreamReader(InputStream in)
     // Creates an InputStreamReader that uses the default charset.
     // Parameters: in - An InputStream

public class FileReader extends InputStreamReader
  public FileReader(String fileName) throws FileNotFoundException
     // Creates a new FileReader, given the name of the file to read from.
     // Parameters: fileName - the name of the file to read from
     // Throws: FileNotFoundException - if the named file does not exist,
     //        is a directory rather than a regular file, or for some other
     //        reason cannot be opened for reading.
```

Higher order functions

```
let rec transform (f: 'a -> 'b) (x: 'a list): 'b list =
 begin match x with
 | [] -> []
 | h :: t -> (f h) :: (transform f t)
 end

let rec fold (combine: 'a -> 'b -> 'b) (base: 'b) (l: 'a list): 'b =
 begin match l with
 | [] -> base
 | h :: t -> combine h (fold combine base t)
 end

let rec filter (f: 'a -> bool) (l: 'a list) : 'a list =
 begin match l with
   | [] -> []
   | h::t -> if f h then h :: filter f t else filter f t
 end
```

Code for questions 3 - 4

```
public class Animal {
   private String name;
   private String sound;

   public Animal(String name, String sound) {
     this.name = name;
     this.sound = sound;
   }

   public String speak() {
     return (name + " says " + sound);
   }

   public void setSound(String sound) {
     this.sound = sound;
   }
}

public class Duck extends Animal {
   public Duck() {
     super("duck", "quack");
   }
}
```

Main method:

```
public static void main(String[] args) {
  Animal d1 = new Duck();
  Animal d2 = new Animal("duck", "quack");
  /* Here */
}
```

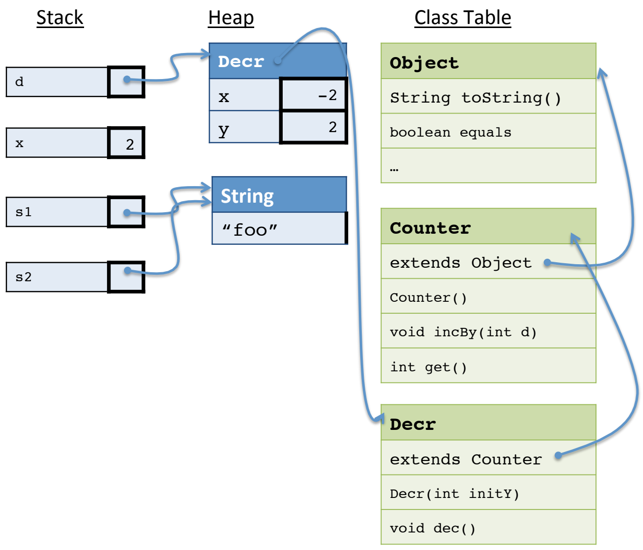
Java ASM

```
public class Counter extends Object {
  private int x;
  public Counter () { super(); this.x = 0; }
  public void incBy(int d) { this.x = this.x + d; }
  public int get() { return this.x; }
}

public class Decr extends Counter {
  private int y;
  public Decr (int initY) { super(); this.y = initY; }
  public void dec() { this.incBy(-this.y); }
}

// ... somewhere in main:
Decr d = new Decr(2);
d.dec();
int x = d.get();
String s1 = new String("foo");
String s2 = new String("foo");
/* Here */
```

The following picture shows the ASM at the point of the computation marked */* Here */*. Note that we do not show the the `String` class in the class table, and that for the `String` object in the heap we just summarize its contents, ignoring its actual internal representation.


Stack
Heap
Class Table
d
x
2
s1
s2
Decr
x
-2
y
2
String
"foo"
Object
String toString()
boolean equals
…
Counter
extends Object
Counter()
void incBy(int d)
int get()
Decr
extends Counter
Decr(int initY)
void dec()