CIS 1200 Final Exam December 22, 2022

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Name (printed): _____

PennKey (penn login id): _____

I certify that I have complied with the University of Pennsylvania's Code of Academic Integrity in completing this examination.

Signature: _____ Date: _____

- There are 120 total points. The exam period is 120 minutes long.
- There are 19 pages in the exam and an Appendix for your reference.
- Please begin by writing your PennKey (e.g., `bcpierce`) at the bottom of all the odd-numbered pages in the rest of the exam.
- Please skim the entire exam first—some of the questions will take significantly longer than others.
- Do not spend too much time on any one question. Be sure to recheck all of your answers.
- We will ignore anything you write on the Appendix.
- For coding problems: aim for accurate syntax, but we will not grade your code style for indentation, spacing, etc.
- If you need extra space for an answer, you may use the scratch page at the end of the exam; make sure to clearly indicate that you have done this in the normal answer space for the problem.
- Good luck!

1. **OCaml and Java Concepts** (20 points total)

   Indicate whether the following statements are true or false.

   (a) True ☐ False ☐

```
let rec iterate (f: 'a -> 'a option) (zero: 'a) (count: int) : 'a =
  begin match f zero with
  | None -> zero
  | Some one -> let res = iterate f one (count + 1) in
                print_endline (string_of_int count);
                res
  end
```

   The function shown above is tail recursive.

   (b) True ☐ False ☐

   In OCaml, if a given **`sig`** has five methods defined, it is possible for the **`struct`** that implements it to have more than five methods.

   (c) True ☐ False ☐

   In the OCaml ASM, stack bindings are mutable by default whereas in the Java ASM, they are immutable by default.

   (d) True ☐ False ☐

   The advantage of enforcing invariants like the Binary Search Tree invariant is that they eliminate the need for testing (because functions like `insert` and `lookup` are guaranteed to be correct).

   (e) True ☐ False ☐

   In OCaml, every mutable reference could refer to `None`.

   (f) True ☐ False ☐

   In our OCaml singly-linked queue implementations, one advantage over the in-built `list` is that we can efficiently add items to the end of the queue.

(g) True ☐ False ☐

In Java, whenever you implement the `Comparable` interface, you should also override the `equals` method compatibly.

(h) True ☐ False ☐

In Java, every subclass class must call the superclass constructor explicitly.

(i) True ☐ False ☐

In Java, every `Exception` must either be caught (with a **`try-catch`** block) or declared (via **`throws`**) in the method signature.

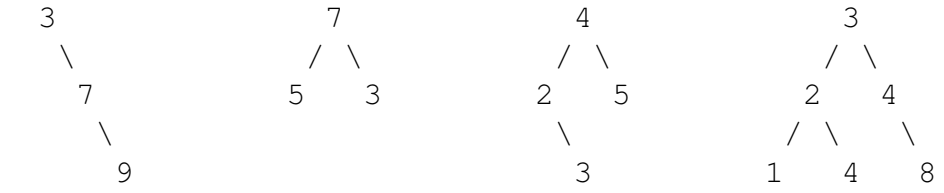
(j) True ☐ False ☐

In Java, the static type of a variable can be the same as the dynamic class of the object the variable refers to.

2. **OCaml: Binary Search Trees and Higher Order Functions** (14 points total)

Recall the definitions of generic `transform` function for lists and of generic binary trees, which are given in Appendix A.

(a) (2 points) Which of the trees below **satisfy** the binary search tree invariant? (Mark all that apply.)



☐ Tree (a) ☐ Tree (b) ☐ Tree (c) ☐ Tree (d)

(b) (3 points) Consider the following modification to the `transform` function that now takes in a tree as input.

```
let rec transform_tree (f: 'a -> 'b) (t: 'a tree) : 'b tree =
  begin match t with
  | Empty -> Empty
  | Node(lt, x, rt) -> Node(transform_tree f lt, f x,
     transform_tree f rt)
  end
```

If the following tree `t` is provided as input to the code shown below...

```
t =      4
        / \
       2   6
          / \
         5   8
```

... what will be the resulting output tree `t1`? Draw it below.

```
let t1 = transform_tree (fun x -> 3 * x) t

t1 =
```

(c) (3 points) Does the `transform_tree` function preserve BST invariants? That is, if the input to the function is a BST and **any** function `f` of type `int->int`, will it *always* return a valid BST as output? (Choose one.)

☐ Yes. If you chose yes, explain why.

☐ No. If you chose no, provide an example of a function `f` as input using the tree `t`. (For the function, you can choose to write code or describe it in words. If it's the latter, please be as precise and accurate as possible.)

(d) (3 points) Consider the following higher order function that takes in a tree as input.

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

If the same tree `t` is provided as input to the code shown below...

```
t =      4
        / \
       2   6
          / \
         5   8
```

...what will be the resulting output tree `t2`? Draw it below.

```
let t2 = mystery (fun x -> x < 6) t
```

```
t2 =
```

(e) (3 points) Does the `mystery` function preserve BST invariants? That is, if the input to the function is a BST and *any* function `f` of type `int->bool`, will it *always* return a valid BST as output? (Choose one.)

☐ Yes. If you chose yes, explain why.

☐ No. If you chose no, provide an example of a function `f` as input using the tree `t`. (For the function, you can choose to write code or describe it in words. If it's the latter, please be as precise and accurate as possible.)

3. **Java Design Problem** (33 points total)

Step 1: Understand the problem For Homework 7 and 8, you worked with `Iterator`s in Java that iterated over a *single* source of data (such as one CSV file). For this design problem, we will create two new kinds of iterators, called `SequenceIterator` and `MergeIterator` that can each draw from *two* sources of data.

A `SequenceIterator` is built from two other iterators, say `first` and `second`. Its `next` method will return items from `first` (by calling `first.next()`) till `first` becomes empty (`first.hasNext()` returns `false`); then it will return items from `second` until it, too, becomes empty.

A `MergeIterator` is also built from two iterators, say `first` and `second`. Its `next` method will first call `first.next()` and return its result, assuming `first.hasNext()` is `true`; the next item it returns is the one returned by calling `second.next()`, assuming `second.hasNext()` is `true`. The third call to `next` returns the next item returned from `first.next()`, and so on, continuing to alternate between the two. If one of the iterators has no more items left, it will use the other iterator for the rest.

For example, if `first` is an iterator over the array `{1, 2, 3}` and `second` is an iterator over the array `{4, 5}`, then...

- Calling `next()` on an iterator obtained from `new SequenceIterator(first,second)` will return `1`, `2`, `3`, `4`, and `5`, after which `hasNext()` will return `false`.
- Calling `next()` on an iterator obtained from `new MergeIterator(first,second)` will return `1`, `4`, `2`, `5`, and `3`, after which `hasNext()` will return `false`.

These examples are written out as JUnit tests on page 9.

(No questions on this page.)

Step 2: Design the interfaces We are considering two classes here—`SequenceIterator` and `MergeIterator`—that both implement the `Iterator<Integer>` interface.

Recall that an `Iterator` is an object that yields a sequence of elements. The Javadocs for the `Iterator<E>` interface are given in Appendix B.

We should also think a bit about the circumstances under which they can raise exceptions.

(a) (4 points) Based on the `Iterator` interface, is it possible for the `next()` method of a sequence or merge iterator to throw an `IOException` (either intentionally or accidentally)?

☐ Yes ☐ No

In one sentence, explain your answer:

(b) (4 points) Based on the interface, is it possible for the `next()` method of a sequence or merge iterator to throw a `NullPointerException` (either intentionally or accidentally)?

☐ Yes ☐ No

In one sentence, explain your answer:

Step 3: Write test code for `SequenceIterator` and `MergeIterator` One benefit of using the `Iterator` interface is that we can create iterators from other datatypes in Java (without needing to use the file system). Here are two example test cases written in this style.

```
@Test
public void testSequenceHasNextAndNext() {
    Integer[] firstElts = {1, 2, 3};
    Integer[] secondElts = {4, 5};
    Iterator<Integer> first = Arrays.asList(firstElts).iterator();
    Iterator<Integer> second = Arrays.asList(secondElts).iterator();

    SequenceIterator sequenced = new SequenceIterator(first, second);
    assertTrue(sequenced.hasNext());
    assertEquals(1, sequenced.next());
    assertEquals(2, sequenced.next());
    assertEquals(3, sequenced.next());
    assertEquals(4, sequenced.next());
    assertEquals(5, sequenced.next());
    assertFalse(sequenced.hasNext());
    assertFalse(first.hasNext());
    assertFalse(second.hasNext());
}
```

```
@Test
public void testMergeHasNextAndNext() {
    Integer[] firstElts = {1, 2, 3};
    Integer[] secondElts = {4, 5};
    Iterator<Integer> first = Arrays.asList(firstElts).iterator();
    Iterator<Integer> second = Arrays.asList(secondElts).iterator();

    MergeIterator merged = new MergeIterator(first, second);
    assertTrue(merged.hasNext());
    assertEquals(1, merged.next());
    assertEquals(4, merged.next());
    assertEquals(2, merged.next());
    assertEquals(5, merged.next());
    assertEquals(3, merged.next());
    assertFalse(merged.hasNext());
    assertFalse(first.hasNext());
    assertFalse(second.hasNext());
}
```

(No questions on this page.)

(a) (4 points) Fill in the blanks in the following test so that all the assertions pass. Each line beginning `assert_____` must be completed with either `True` or `False`. The other blanks should be filled with numbers.

```
@Test
public void mergeSame() {
    Integer[] elts = {1, 2, 3};
    Iterator<Integer> iter = Arrays.asList(elts).iterator();

    MergeIterator merged = new MergeIterator(iter, iter);

    assertEquals(1, merged.next());

    assertEquals(________, iter.next());

    assertEquals(________, merged.next());

    assert__________________(merged.hasNext());

    assert__________________(iter.hasNext());
}
```

(b) (6 points) Again, fill in the blanks so that all the assertions pass.

```
@Test
public void nestedMerge() {
    Integer[] firstElts = {1, 2};
    Iterator<Integer> first = Arrays.asList(firstElts).iterator();

    Integer[] secondElts = {3, 4};
    Iterator<Integer> second = Arrays.asList(secondElts).iterator
        ();

    Integer[] thirdElts = {5, 6};
    Iterator<Integer> third = Arrays.asList(thirdElts).iterator();

    MergeIterator merged12 = new MergeIterator(first, second);
    MergeIterator merged123 = new MergeIterator(merged12, third);

    assertEquals(1, merged123.next());

    assertEquals(__________, merged123.next());

    assertEquals(__________, merged123.next());

    assertEquals(__________, merged123.next());

    assertEquals(__________, merged123.next());

    assert_________________(merged12.hasNext());

    assert_________________(third.hasNext());
}
```

Step 4: Implement `MergeIterator` (15 points)

Complete the code for `MergeIterator`. Your implementation should satisfy the `Iterator<Integer>` interface.

Hint: You might want to think about what *invariant* the state of your iterator maintains.

```
public class MergeIterator implements Iterator<Integer> {

    private Iterator<Integer> first;
    private Iterator<Integer> second;
    // Add fields as needed:









    // you can assume first and second are not null
    public MergeIterator (Iterator<Integer> first, Iterator<Integer>
        second) {
        this.first = first;
        this.second = second;









    }

    @Override
    public boolean hasNext() {









    }
    // space for next() is on the following page...
```

```
        @Override
        public Integer next() {

        }
    }
```

4. **Java Subtyping and Dynamic Dispatch** (24 points total)

This problem refers to three interfaces and several classes that might appear in program about Animals. You can find them in Appendix C.

(a) (2 points) Which lines of code are example uses of subtype polymorphism in Java? (Mark all that apply.)

☐ Line 84 ☐ Line 85 ☐ Line 86 ☐ Line 87 ☐ Line 89

(b) (2 points) Which lines of code are example uses of parametric polymorphism (i.e., generics) in Java? (Mark all that apply.)

☐ Line 84 ☐ Line 85 ☐ Line 86 ☐ Line 87 ☐ Line 89

(c) (4 points)

```
_____ winter = new Dolphin();
```

Which type can be correctly used for the declaration of `winter` above? (Mark all that apply.)

☐ `Animal`	☐ `Flyer`	☐ `Penguin`	☐ `Swimmer`
☐ `Mammal`	☐ `Dolphin`	☐ `Bat`	☐ `Object`

Which of the following lines is legal Java code that will not cause any compile-time (i.e., type checking) or run-time errors?

If it is legal code, check the "Legal Code" box and answer the questions that follow it. If it is not legal, check one of the "Not Legal" options and explain why.

You can assume each option below is independent and written after line 91 in the `main` method (as shown in the Appendix).

(d) (3 points)

```
Animal dog = new Mammal();
```

☐ Legal Code

A. The static type of `dog` is _____ .

B. The dynamic class of `dog` is _____ .

☐ Not Legal — Will compile, but will throw an `Exception` when run

☐ Not Legal — Will not compile

Reason for not legal (in either of the two illegal cases above):

_____

(e) (3 points)

```
Mammal dolphin = new Dolphin();
System.out.println(dolphin.commonName());
```

☐ Legal Code

The code above will print (Choose all that apply.)

☐ "Mammal"

☐ "Dolphin"

☐ Not Legal — Will compile, but will throw an `Exception` when run

☐ Not Legal — Will not compile

Reason for not legal (in either of the two illegal cases above):

_____

(f) (3 points)

```
Flyer bat = new Bat();
bat.echoLocate();
```

☐ Legal Code

The code above will print (Choose all that apply.)

☐ "Bat"

☐ "Fly, bat, fly!"

☐ "<<<eeek>>>"

☐ Not Legal — Will compile, but will throw an `Exception` when run

☐ Not Legal — Will not compile

Reason for not legal (in either of the two illegal cases above):

_____

(g) (3 points)

```
Swimmer swim = new Dolphin();
Animal animal = (Animal) swim;
System.out.println(animal.distinguishingFeature());
```

☐ Legal Code

A. The static type of `animal` is _____ .

B. The dynamic class of `animal` is _____ .

C. The code above will print (Choose all that apply.)

☐ "Being in Titanic"

☐ "Hair"

☐ "Tuxedo Feather Pattern"

☐ Not Legal — Will compile, but will throw an `Exception` when run

☐ Not Legal — Will not compile

Reason for not legal (in either of the two illegal cases above):

_____

(h) (4 points)

```
Swimmer swim = new ___???___();
Animal animal = (Dolphin) swim;
System.out.println(animal.distinguishingFeature());
```

What can be used on the first line (instead of the `???`) so that the code successfully compiles *but throws an exception when run*? (Mark all that apply.)

☐ `Swimmer` ☐ `Bat` ☐ `Penguin` ☐ `Object`

5. **Java Swing Programming** (29 points total)

Appendix D shows the code for a simplified version of the `PaintE` application that was demoed in lecture. The following questions use this code to test your understanding of both Swing and Java programming idioms.

(a) (2 points) The class `PointMode` defined on line 8 implements the Swing interface `MouseMotionListener`.

True ☐ False ☐

(b) (2 points) How will the program's behavior change if we delete the call to `canvas.repaint()` on line 67? (Select one.)

- ☐ Drawing points will work fine, but lines will only appear after another point is entered (by going back to Point mode and clicking in the drawing area).
- ☐ Drawing points will work fine, and lines will be drawn as usual after the mouse is released, but the "preview" behavior of line drawing will stop working.
- ☐ Nothing at all will ever be displayed – just a blank window.
- ☐ The initial GUI will be displayed, but no shapes will ever be drawn.
- ☐ No change in behavior.

(c) (3 points) How many instances of the class `PointMode` are created during a whole run of the program? (Select one.)

- ☐ None.
- ☐ At most one.
- ☐ Exactly one.
- ☐ One for every time the user enters a line (by clicking the drawing canvas twice while in line-drawing mode).
- ☐ Something else: _____

(d) (3 points) How many instances of the class `LineStartMode` are created during a whole run of the program? (Select one.)

- ☐ None.
- ☐ At most one.
- ☐ Exactly one.
- ☐ One for every time the user enters a line (by clicking the drawing canvas twice while in line-drawing mode).
- ☐ One for every time the user enters a line (by clicking the drawing canvas twice while in line-drawing mode), *plus* one when the program starts running.
- ☐ Something else: _____

(e) (3 points) How many instances of the class `LineEndMode` are created during a whole run of the program? (Select one.)

- ☐ None.
- ☐ At most one.
- ☐ Exactly one.
- ☐ One for every time the user enters a line (by clicking the drawing canvas twice while in line-drawing mode).
- ☐ One for every time the user enters a line (by clicking the drawing canvas twice while in line-drawing mode), *plus* one when the program starts running.
- ☐ Something else: _____

(f) (8 points) At the moment, lines and points are always drawn in black. If we wanted to give the user the ability to draw in multiple colors, what would we need to *add* or *change* in the existing code? (Just summarize the changes briefly in English – no need to actually write anything in Java. Make sure to consider how this change would affect the fields of the `PaintE` class, the construction of the GUI, and the behavior of GUI elements.)

(g) (8 points)

Suppose we wanted to let the user draw rectangles in addition to lines and points. The "look and feel" should be similar to adding lines: when in Rectangle mode, the user can click, drag, and release the mouse to add a new rectangle to the picture; while dragging, a preview of the rectangle will be drawn. What do we need to add to the code in Appendix D to implement this new feature? (Just describe the additions in English—no need to write any Java code.)

Scratch Space

*Use this page for work that you do not want us to grade. If you run out of space elsewhere in the exam and you **do** want to put something here that we should grade, make sure to put a clear note in the normal answer space for the problem in question.*