CIS 120 Final Exam December 17, 2021

SOLUTIONS

1. **Java Concepts** (10 points)

Recall that, in Java, a class may implement several interfaces but may extend only one parent class. Suppose that we were to change Java so that a class can extend two or more classes. Then the following declaration would be allowed, which means that classes `D` and `E` are both parents of `C` in the class hierarchy:

```
class C extends D, E implements I {
  /*  C's fields and methods */
}
```

(a) Briefly describe one *benefit* for structuring software that would be allowed by this change, and give an example use case. Be specific.

Answer: Since this feature would allow a class `C` to inherit method implementations from both `D` and `E`, we could have a class `Color` with methods for getting and setting color values, and a class `ShapeImpl` that implements basic shape methods (size, position, etc.). We could then implement a `ColoredShape` by extending `Color` and `ShapeImpl`.

Grading Rubric

- 2 points - for mentioning that the two parent classes could implement distinct methods
- 2 points - for giving an example (that is at least slightly plausible and specific)

(b) Briefly describe one *problem* that this change would cause, and give an example. Be specific.

Answer: This feature causes a problem if both `D` and `E` implement the *same* method `m()` that is required by the interface `I`. Then code like the following would lead to ambiguity in the dynamic dispatch search for which `m` method to use:

```
static void method(I obj) {
  obj.m();   /* This method dispatch is ambiguous */
}

/* somewhere in main() */
method(new C());
```

Note: this is called the "diamond import problem" and is a classic issue with "multiple inheritance".

Grading Rubric

- 2 points - for observing that the problem arises if the two parent classes implement the *same* method or *public* fields in incompatible ways
- 2 points - for saying that it causes ambiguity in dynamic dispatch or field lookup
- 2 points - for giving an example that demonstrates the ambiguity (via a method call)

2. **OCaml and Java Concepts** (20 points) (2 points each) Indicate whether the following statements are true or false.

a. True ☐ False ☒

In OCaml, the intended behavior of an abstract type is defined by its interface, its properties, and its implementation.

b. True ☒ False ☐

In OCaml, it is possible to use the sequencing operator `;` to execute multiple expressions and have multiple side-effects.

c. True ☒ False ☐

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

d. True ☒ False ☐

In the OCaml ASM, a closure stores the required stack bindings on the heap with the function body.

e. True ☐ False ☒

In our OCaml GUI libraries, it is not possible for container widgets (like `hpair`) to handle events.

f. True ☐ False ☒

In the Java ASM, **`static`** variables are stored on the stack.

g. True ☒ False ☐

In Java, dynamic dispatch of a method invocation is guaranteed to find an appropriate method body in the class table, if the code successfully compiled.

h. True ☒ False ☐

In Java, it is possible to have multiple **`catch`** blocks, but it is possible that the order in which the blocks are written causes a compile-time error.

i. True ☒ False ☐

In Java, the `length` of an array is immutable.

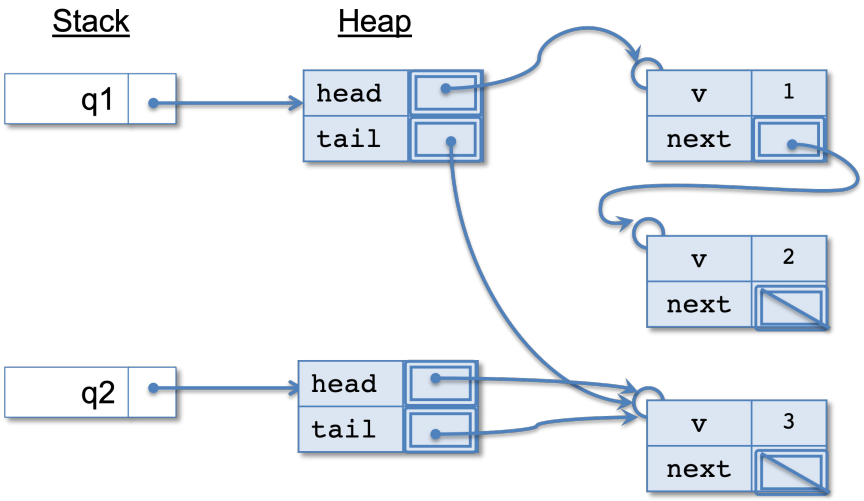
j. True ☐ False ☒

In Java, the static type must be a subtype of the dynamic class of an object.

3. **OCaml Higher Order Functions, Queues, and ASM** (28 points total)

Recall the definition of singly-linked queues and their invariants from Homework 4. These are available in Appendix A.

Consider the Stack and Heap for the ASM shown below.



(a) (2 points) Does the queue `q1` satisfy the queue invariants?

☐ Yes ☒ No

(b) (2 points) Does the queue `q2` satisfy the queue invariants?

☒ Yes ☐ No

Next, we'll create a modified version of the higher order function `transform` (from Homework 3 and 4) that works on queues. The code is shown below:

```
let rec transform_queue (f: 'a qnode -> unit) (q: 'a queue) : unit =
  let rec loop (no: 'a qnode option) : unit =
    begin match no with
    | None -> ()
    | Some n -> let next = n.next in
                f n;
                loop next
    end
  in loop q.head
```

(c) (2 points) Is the `transform_queue` function tail recursive?

☒ Yes ☐ No

(d) (4 points) Assuming that `f` can only access its input argument (and nothing else on the stack or heap), does the `transform_queue` function always preserve the queue invariants?

☐ Yes ☒ No

Explain why:

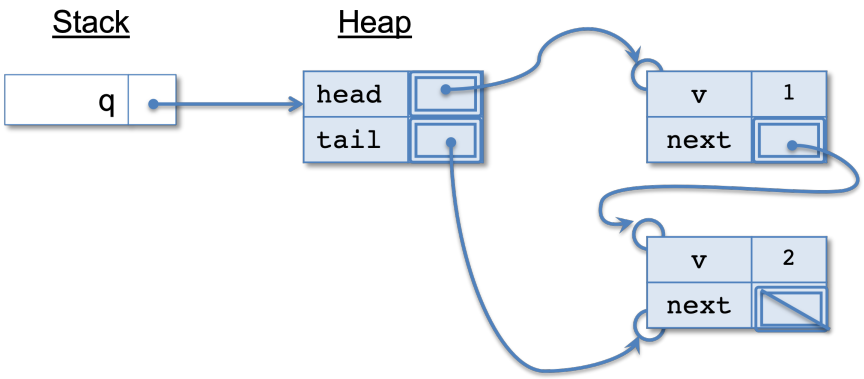
Since the `f` function directly manipulates the `'a qnode`,

it could violate the queue invariants, e.g., by setting the `next` to `None`.

Grading scheme: +2 Selected correct option AND (+0.5 for partially correct reason OR +2 for completely correct reason)

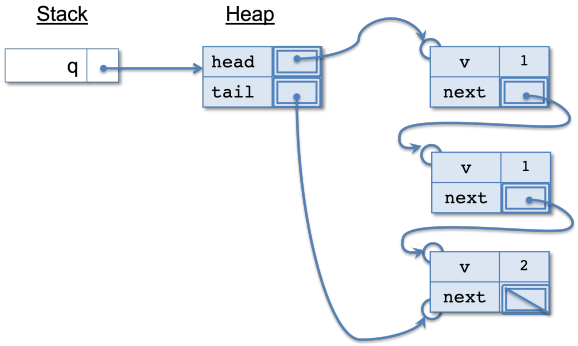
(e) (8 points) Consider the `mystery` function and the queue `q` as shown below.

```
let mystery (no: 'a qnode) : unit =
  if no.next <> None then
    let new_node = {v = no.v; next = no.next} in
    no.next <- Some new_node
```



Next, we perform the function call `transform_queue mystery q`.

Draw the ASM stack and heap after the function call is completed. For the purposes of this question, you can ignore everything on the Stack and Heap, other than what is part of the queue `q`.
(Note that `<>` is structural inequality in OCaml.)



Finally, we'll create a modified version of the higher order function `fold` (from Homework 3 and 4) that works on queues. The code is shown below:

```
let rec fold_queue (combine: 'a -> 'b -> 'b) (base: 'b) (q: 'a queue) : 'b =
  let rec loop (no: 'a qnode option) : 'b =
    begin match no with
    | None -> base
    | Some n -> combine n.v (loop n.next)
    end
  in loop q.head
```

(f) (2 points) Is the `fold_queue` function tail recursive?

☐ Yes ☒ No

(g) (4 points) Assuming that `combine` can only access its input arguments (and nothing else on the stack or heap), does the `fold_queue` function always preserve the queue invariants?

☒ Yes ☐ No

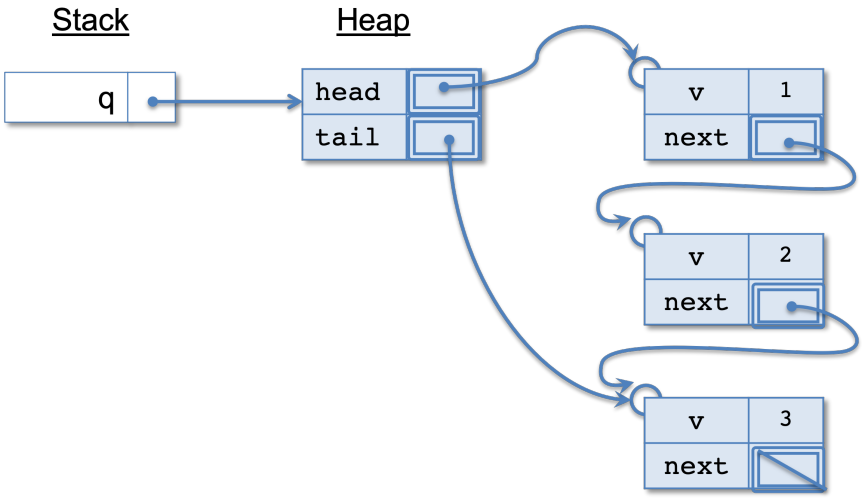
Explain why:

Since the `fold` function only manipulates the `'a qnode`'s `v`,

it can never change the structure of the queue. Hence it will preserve the invariants.

Grading scheme: +2 Selected correct option AND (+0.5 for partially correct reason OR +2 for completely correct reason)

(h) (4 points) Consider the function call `fold_queue (fun hd acc -> hd * acc) 1 q` where the queue `q` is shown below.



What will be the result of the above function call? (1–2 sentences will be sufficient here.)

The code will find the product of the `qnode`'s `v` values.

In this case, it will be 6. It *will not* modify the queue.

4. **Java SubTyping, Inheritance, and Exceptions** (29 points)

This problem refers to two interfaces and several classes that might be part of a program for working with the Library book series by Genevieve Cogman. You can find them in Appendix B.

(a) (2.5 points) Which of the following classes are an example of simple inheritance in Java (either explicitly or implicitly)? (Mark all that apply.)

☒ `Librarian` ☒ `Fae` ☒ `Dragon` ☐ `LiteraryDetective` ☒ `SubTyping`

(b) (2.5 points) Which lines of code are example uses of subtype polymorphism in Java? (Mark all that apply.)

☐ Line 65 ☒ Line 66 ☒ Line 68 ☐ Line 69 ☒ Line 71

(c) (2.5 points) Which lines of code are example uses of parametric polymorphism (i.e., generics) in Java? (Mark all that apply.)

☐ Line 65 ☐ Line 66 ☐ Line 68 ☐ Line 69 ☒ Line 71

(d) (3.5 points)

```
_______ vale = new LiteraryDetective();
```

Which types (there may be one or more) can be correctly used for the declaration of `vale` above?

☒ `Human` ☒ `TravelsBetweenWorlds` ☐ `Librarian` ☒ `Fae`
☐ `Dragon` ☒ `LiteraryDetective` ☒ `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 71 in the `main` method (as shown in the Appendix).

(e) (3 points)

```
TravelsBetweenWorlds lordSilver = new Fae();
```

☒ Legal Code

A. The static type of `lordSilver` is `TravelsBetweenWorlds`.

B. The dynamic class of `lordSilver` is `Fae`.

☐ 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)

```
Fae vale = new LiteraryDetective();
printName(vale);
```

☐ Legal Code

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

- ☐ "Vale (aka Sherlock Holmes)"
- ☐ "This method is abstract and not implemented yet."

☐ 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):

`Fae` is not a subtype of `Human`

(g) (3 points)

```
Fae vale = new LiteraryDetective();
System.out.println(vale.travel());
```

☒ Legal Code

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

- ☐ "I need to create a portal using a book"
- ☐ "Only powerful Fae can travel between worlds"
- ☐ "I can carry a Fae or a Librarian with me"
- ☒ "I am Vale (aka Sherlock Holmes), but I need a Librarian to help"

☐ 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) (3 points)

```
travellers.add(princeKai);
System.out.println(travellers.contains(princeKai));
```

☐ Legal Code

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

- ☐ **`true`**
- ☐ **`false`**

☒ 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):

Cannot cast from `Dragon` to `Comparable`, however code will compile

For the following two parts, we have created two new `Exception` classes:
`FaeTriedToEnterLibraryException` that is a subtype of `Exception`, but not `RuntimeException`.
`LiteraryDetectiveFoundAFaeNemesisException` that is a subtype of `RuntimeException`.
(Note that `a instanceof b` checks whether `a`'s dynamic class is a subtype of `b`.)

(i) (3 points)

```
public void travelToLibrary(TravelsBetweenWorlds t) {
    if (t instanceof Fae) {
        throw new FaeTriedToEnterLibraryException();
    } else {
      System.out.println(t.travel());
    }
}
// somewhere else
travelToLibrary(new Dragon());
```

☐ Legal Code

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

- ☐ "Only powerful Fae can travel between worlds"
- ☐ "I can carry a Fae or a Librarian with me"
- ☐ "I am Vale (aka Sherlock Holmes), but I need a Librarian to help"
- ☐ It will print something other than the options shown above.

☐ 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):

ANSWER: Since FaeTriedToEnterLibraryException is a checked exception, the code won't compile — we need either a **`try`**/**`catch`** or we need to specify that the method **`throws`** `FaeTriedToEnterLibraryException`.

(j) (3 points)

```
public void nemesis(LiteraryDetective detective, TravelsBetweenWorlds t) {
    if (t instanceof Fae) {
        throw new LiteraryDetectiveFoundAFaeNemesisException();
    } else {
      System.out.println(detective.getName() + " found a nemesis");
    }
}
// somewhere else
nemesis(new LiteraryDetective(), new Fae());
```

☐ Legal Code

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

- ☐ "Vale (aka Sherlock Holmes) found a nemesis"
- ☐ "Irene found a nemesis"
- ☐ It will print something other than the options shown above.

☒ 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):

ANSWER: Since LiteraryDetectiveFoundAFaeNemesisException is *not* a checked exception, the code will compile, but in this case, it will throw the `LiteraryDetectiveFoundAFaeNemesisException`.

Grading scheme: For (a–d), +0.5 for each option correctly answered

Grading scheme: For Illegal Code (f, g, i, j), +1.5 Selected correct option AND (+0.5 for partially correct reason OR +1.5 for completely correct reason)

Grading scheme: For (e), +1 Selected correct option AND +1 for each type correctly answered

Grading scheme: For (g), +1.5 Selected correct option AND +1.5 for print option correctly answered

5. **Java Programming** (33 points total)

When working with sets of data, one frequently useful operation is the ability to "group" subsets of the data that are related in some way. For example, if we have a set of CIS 120 students, we might want to group them by which recitation sections they are in. Or we might want to take a set of `String`s and group them by their lengths. In this problem we will add a method `groupBy` to Java's `Set` collection functionality by implementing a class called `GroupableSet`. Appendix E contains the relevant part of the Java Docs for the interfaces we will need.

Step 1: Understand the problem: (6 points) As an example, suppose we have the set of strings shown below (written informally, not using Java notation):

```
GroupableSet<String> set1 = {"ddd", "a", "bb", "cc" , "eee"}
```

We want `set1.groupBy(classifier)` to produce the following `Map`, whose integer keys are the string lengths found in `set1`. Each key's value is a `Set` containing the subset of `set1` of strings of that length:

```
set1.groupBy(classifier) =
  key   value
  1 ->  {"a"}              // group of length 1 strings
  2 ->  {"bb", "cc"}       // group of length 2 strings
  3 ->  {"ddd", "eee"}     // group of length 3 strings
```

For simplicity, we will assume that each "group" is identified by an `Integer` and that `groupBy` takes an input, called `classifier`, which determines to which group each element of the set belongs. This `classifier` is an object that provides an `apply` method taking an element returning an `Integer` for that element's group. For the example above, `classifier.apply(s) = s.length()`, where `s` is a `String`.

(a) Suppose that we add the empty `String` `""` to the `GroupableSet set1` mentioned above. What would be the key for `""` in the resulting map after grouping by length? (Choose one.)

☐ **`null`** ☒ `0` ☐ `1` ☐ `2` ☐ there is no such key

(b) Suppose we create a different `classifier2` object such that `classifier2.apply(s) = 2`. Which of the following are true statements about the map resulting from calling `set1.groupBy(classifier2)`, *i.e.*, we use this new classifier on the same `set1` from above? (Mark *all* that apply.)

☐ The map will contain the key `1`
☒ The map will contain the key `2`
☐ The map will contain the key `3`
☒ All of the elements will be in one group.
☐ There will be one element in each group.

(c) Suppose we create a `GroupableSet<Integer> set3` with elements `{0, 1, 2, 3, 4, 5}` and we create a `classifier3` such that `classifier3.apply(x) = x`. Which of the following are true statements about the map resulting from calling `set3.groupBy(classifier3)`? (Mark *all* that apply.)

☒ The map will contain the key `1`
☒ The map will contain the key `2`
☒ The map will contain the key `3`
☐ All of the elements will be in one group.
☒ There will be one element in each group.

Step 2: Design the interface (11 points)

We will implement a class called `GroupableSet<E>` that implements the `Set<E>` interface and, additionally, provides the `groupBy` method. Note (from the Java Docs in Appendix E) that the `Function<T,R>` interface indicates an object that has an `R apply(T t)` method. Based on the desired behavior above, the type of the `groupBy` method we use is as follows:

```
Map<Integer,Set<E>> groupBy(Function<E,Integer> classifier)
```

(d) The type of the `groupBy` method is an example of parametric polymorphism (a.k.a. a generic type).
☒ True ☐ False

Now consider the example uses of `groupBy` given by the classes `MainA`, `MainB`, `MainC`, and `MainD` as shown in Appendix C. Answer each question below. If the answer is "false" give a brief explanation.

Grading scheme: 2 points each - for (f) (the only false one): 2 points for the explanation about the mismatched `Function` *types.*

(e) The code in `MainA` is well typed. (Has no compile-time errors.)
☒ True
☐ False because

(f) The code in `MainB` is well typed. (Has no compile-time errors.)
☐ True
☒ False because

`Classifier2` implements `Function<Integer,Integer>` not `Function<String, Integer>`

(g) The code in `MainC` is well typed. (Has no compile-time errors.)
☒ True
☐ False because

(h) The code in `MainD` is well typed. (Has no compile-time errors.)
☒ True
☐ False because

(i) Which classes exhibit the use of *anonymous inner classes*? (Mark all that apply.)
☐ `MainA` ☐ `MainB` ☒ `MainC` ☒ `MainD`

Step 3: Write test cases (6 points)

Recall that, when testing a method like `groupBy`, it is often helpful to think about the *properties* that we expect to hold, especially in relation to other operations. Such properties can usually be turned into test cases.

Assume the following:

- `set` is an object of type `GroupableSet<String>`
- `classifier` is an object of type `Function<String,Integer>`
- `map` is an object of type `Map<Integer,Set<String>>` returned by `set.groupBy(classifier)`
- `k`, `k1`, and `k2` are **`int`** values (which can be used implicitly as `Integer` objects)
- None of the objects are **`null`** and none of the methods raise exceptions. (We would write other kinds of test cases for those situations.)

Each of the following properties relates `groupBy` to the `Set<E>`, `Map<Integer,Set<E>>`, and `Function<E,Integer>` interface operations. Choose one option for each blank to make the property a correct description of the intended behavior of `groupBy`.

(j) For every `o`, if _____ then there is some `k` such that `k == classifier.apply(o)` and `map.get(k).contains(o)`.

- ☐ `!map.containsKey(k)`
- ☐ `map.containsKey(k)`
- ☐ `!set.contains(o)`
- ☒ `set.contains(o)`

(k) For every `o` and `k`, if _____ then `set.contains(o)`.

- ☐ `!map.get(k).contains(o)`
- ☒ `map.get(k).contains(o)`
- ☐ `!map.containsKey(k)`
- ☐ `map.containsKey(k)`

(l) For every `o`, `k1`, and `k2`, if `map.get(k1).contains(o)` and `map.get(k2).contains(o)` then _____.

- ☒ `k1 == k2` and `k1 == classifier.apply(o)`
- ☐ `k1 != k2` and `k1 == classifier.apply(o)`
- ☐ `k1 == k2` and `k1 != classifier.apply(o)`
- ☐ `k1 != k2` and `k1 != classifier.apply(o)`

Step 4: Implement the code (10 points)

We want every `GroupableSet<E>` object to be an instance of `Set<E>`, but we don't want to have to re-implement all of the `Set` interface operations to achieve that. Recall that an *adapter* class provides default implementations of a given interface. Appendix D gives an appropriate `SetAdapter<E>` implementation of the `Set<E>` interface that we will use below as the basis for `GroupableSet`. Note that it contains the *private* field `set`.

Now complete the implementation of the `groupBy` method. You will need to create new `Set` and `Map` objects—we have imported the `TreeSet` and `TreeMap` classes for you.

```
import java.util.Map;
import java.util.Set;
import java.util.TreeMap;
import java.util.TreeSet;
import java.util.function.Function;

public class GroupableSet<E> extends SetAdapter<E> implements Set<E> {

    public GroupableSet(Set<E> set) {
        super(set);
    }

    public Map<Integer,Set<E>> groupBy(Function<E,Integer> classifier) {
        Map<Integer,Set<E>> groups = new TreeMap<Integer,Set<E>>();

        for(E elt : this) {
            Integer group = classifier.apply(elt);
            if (groups.containsKey(group)) {
                Set<E> elts = groups.get(group);
                elts.add(elt);
            } else {
                Set<E> elts = new TreeSet<E>();
                elts.add(elt);
                groups.put(group, elts);
            }
        }
        return groups;
    }
```

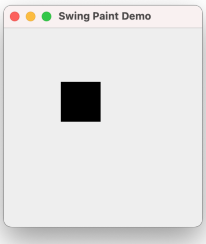
Grading Rubric:

- 2 points - creating a new `TreeMap` of the appropriate type.
- 2 points - proper iteration: i.e., using either `self.Iterator()` or for-each loop with **`this`**
- 1 points - correctly using `classifier.apply` on the iterated element
- 1 points - checking the map being constructed by using `containsKey`
- 2 points - adding the element to the correct group (one point per branch)
- 1 point - correctly constructing a new `TreeSet` if the group doesn't exist
- 1 point - adding the new set to the map with the right key

```
    }
}
```

6. **Java Swing Programming** (10 points)

The code in Appendix F implements a simple Java GUI program in which a 50x50 black box follows the mouse cursor around the window. It looks like this (the mouse cursor is not shown):



The following true/false questions concern this application and Java Swing programming in general.

a. True ☒ False ☐

The type `MyPanel` is a subtype of `Object`.

b. True ☐ False ☒

Lines 5–9 create a new object whose static type and dynamic class are, both, `Runnable`.

c. True ☒ False ☐

If we changed line 27 from `addMouseMotionListener` to `addMouseListener` then the black box would not follow the mouse cursor.

d. True ☐ False ☒

If we changed line 27 from **`new`** `MouseAdapter` to **`new`** `MouseMotionListener`, the code would still compile.

e. True ☐ False ☒

The instance variables `x` and `y`, declared on lines 23 and 24, can be declared as **`final`**.

f. True ☒ False ☐

There are two `@Override` annotations in the code. If we removed them, the code would still compile.

g. True ☒ False ☐

The `mouseMoved` method on line 28 is called by the Swing event loop in reaction to the user moving the mouse in the main window of the application.

h. True ☐ False ☒

The `paintComponent` method on line 42 is only invoked once, at the start of the application.

i. True ☒ False ☐

The anonymous inner class defined on line 27 implements or inherits all members of the `MouseMotionListener` interface.

j. True ☐ False ☒

The `GUI` class and the `createAndShowGUI()` method share the same stack and heap in the Java ASM.

CIS 120 Final Exam — Appendices

A OCaml Queue Code and Invariants

```
(* INVARIANT: *)
(* - q.head and q.tail are either both None, or *)
(* - q.head and q.tail both point to Some nodes, and *)
(*    - q.tail is reachable by following 'next' pointers from q.head *)
(*    - q.tail's next pointer is None *)

type 'a qnode = { v: 'a;
                  mutable next: 'a qnode option }

type 'a queue = { mutable head: 'a qnode option;
                  mutable tail: 'a qnode option }
```

B Java Code for SubTyping

```
1  interface Human {
2      public String getName();
3  }
4
5  interface TravelsBetweenWorlds {
6      public String travel();
7  }
8
9  class Librarian implements Human, TravelsBetweenWorlds {
10
11     private String name;
12
13     public Librarian(String name) {
14         this.name = name;
15     }
16
17     @Override
18     public String travel() {
19         return "I need to create a portal using a book";
20     }
21
22     @Override
23     public String getName() {
24         return name;
25     }
26 }
27
28 class Fae implements TravelsBetweenWorlds {
29
30     @Override
31     public String travel() {
32         return "Only powerful Fae can travel between worlds";
33     }
34 }
35
36 class Dragon implements TravelsBetweenWorlds {
37
38     @Override
39     public String travel() {
40         return "I can carry a Fae or a Librarian with me";
41     }
42 }
43
44 class LiteraryDetective extends Fae implements Human {
45
46     @Override
47     public String getName() {
48         return "Vale (aka Sherlock Holmes)";
49     }
50
51     @Override
52     public String travel() {
53         return "I am " + getName() + ", but I need a Librarian to help";
54     }
```

```
55 }
56
57 public class SubTyping {
58
59     public static void printName(Human human) {
60         System.out.println(human.getName());
61     }
62
63     public static void main(String[] args) {
64
65         Librarian irene = new Librarian("Irene");
66         TravelsBetweenWorlds princeKai = new Dragon();
67
68         printName(irene);
69         princeKai.travel();
70
71         Set<TravelsBetweenWorlds> travellers = new TreeSet<TravelsBetweenWorlds>();
72
73
74     }
75
76
77 }
```

C Java Code for `groupBy` Examples

```
1  class Global {
2      static GroupableSet<String> set = /* ... omitted ... */
3  }
4
5  class Classifier1 implements Function<String, Integer> {
6      @Override
7      public Integer apply(String s) {
8          return s.length();
9      }
10 }
11
12 class Classifier2 implements Function<Integer, Integer> {
13     @Override
14     public Integer apply(Integer x) {
15         return x;
16     }
17 }
18
19 class MainA {
20     public static void main(String[] args) {
21         Map<Integer, Set<String>> m = Global.set.groupBy(new Classifier1());
22     }
23 }
24
25 class MainB {
26     public static void main(String[] args) {
27         Map<Integer, Set<String>> m = Global.set.groupBy(new Classifier2());
28     }
29 }
30
31 class MainC {
32     public static void main(String[] args) {
33         Map<Integer, Set<String>> m =
34           Global.set.groupBy(new Function<String, Integer>() {
35             @Override
36             public Integer apply(String s) {
37                 return s.length();
38             }
39         });
40     }
41 }
42
43 class MainD {
44     public static void main(String[] args) {
45         Map<Integer, Set<String>> m = Global.set.groupBy(s -> s.length());
46     }
47 }
```

D Java Code For `SetAdapter`

```
import java.util.Iterator;
import java.util.Set;

/*
  This class provides a "wrapper" implementation that delegates
  each Set method to the set provided to the constructor.
 */
public class SetAdapter<E> implements Set<E> {

    /* The set to which operations are delegated */
    private Set<E> set;

    public SetAdapter(Set<E> set) {
        this.set = set;
    }

    @Override
    public boolean isEmpty() {
        return this.set.isEmpty();
    }

    @Override
    public boolean add(E e) {
        return this.set.add(e);
    }

    @Override
    public boolean contains(Object o) {
        return this.set.contains(o);
    }

    @Override
    public Iterator<E> iterator() {
        return this.set.iterator();
    }

}
```

E Java Docs

interface `Set<E>` (Excerpt)

Type Parameters:

- `E` - the type of elements in this set

---

boolean `add(E e)`

Adds the specified element to this set if it is not already present (optional operation).

- **Returns:** **`true`** if this set did not already contain the specified element
- **Throws:**

  `UnsupportedOperationException` - if the add operation is not supported by this set

  `ClassCastException` - if the class of the specified element prevents it from being added to this set

  `NullPointerException` - if the specified element is null and this set does not permit null elements

  `IllegalArgumentException` - if some property of the specified element prevents it from being added to this set

---

boolean `contains(Object o)`

- **Returns:** **`true`** if this set contains the specified element

---

boolean `isEmpty()`

- **Returns:** **`true`** if this set contains no elements.

`Iterator<E> iterator()`

- **Returns:** an iterator over the elements in this set

interface `Map<K,V>` (Excerpt)

Type Parameters:

- `K` - the type of keys maintained by this map
- `V` - the type of mapped values

---

boolean `containsKey(Object key)`

- **Returns:** **`true`** if this map contains a mapping for the specified key.

`V get(Object key)`

- **Returns:** the value to which the specified key is mapped, or null if this map contains no mapping for the key.

`V put(K key, V value)`

Associates the specified value with the specified key in this map (optional operation). If the map previously contained a mapping for the key, the old value is replaced by the specified value. (A map `m` is said to contain a mapping for a key `k` if and only if `m.containsKey(k)` would return **`true`**.)

- **Parameters:**

  `key` - key with which the specified value is to be associated

  `value` - value to be associated with the specified key

- **Returns:** the previous value associated with key, or **`null`** if there was no mapping for `key`. (A **`null`** return can also indicate that the map previously associated **`null`** with `key`, if the implementation supports **`null`** values.)

interface `Iterator<E>` (Excerpt)

---

boolean `hasNext()`

- **Returns:** **`true`** if the iteration has more elements

`E next()`

- **Returns:** the next element in the iteration
- **Throws:** `NoSuchElementException` - if the iteration has no more elements

interface `Function<T,R>`
Type Parameters:

- `T` - the type of the input to the function
- `R` - the type of the result of the function

`R apply(T t)`

Applies this function to the given argument.

- **Parameters:** `t` - the function argument
- **Returns:** the function result

F Java Swing Code

```java
// library imports omitted to save space (this code compiles)
public class GUI {

    public static void main(String[] args) {
        SwingUtilities.invokeLater(new Runnable() {
            public void run() {
                createAndShowGUI();
            }
        });
    }

    static void createAndShowGUI() {
        JFrame f = new JFrame("Swing Paint Demo");
        f.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        f.add(new MyPanel());
        f.pack();
        f.setVisible(true);
    }
}

@SuppressWarnings("serial")
class MyPanel extends JPanel {
    private int x;
    private int y;

    public MyPanel() {
        addMouseMotionListener(new MouseAdapter() {
            public void mouseMoved(MouseEvent e) {
                x = e.getX();
                y = e.getY();
                repaint();
            }
        });
    }

    @Override
    public Dimension getPreferredSize() {
        return new Dimension(250, 250);
    }

    @Override
    public void paintComponent(Graphics g) {
        super.paintComponent(g);
        g.setColor(Color.BLACK);
        g.fillRect(x, y, 50, 50);
    }

}
```

Note: the boxes in the picture below don't mean anything—the diagram is copied from the course lecture slides.

Two interfaces for mouse listeners

```
interface MouseListener extends EventListener {
  public void mouseClicked(MouseEvent e);
  public void mouseEntered(MouseEvent e);
  public void mouseExited(MouseEvent e);
  public void mousePressed(MouseEvent e);
  public void mouseReleased(MouseEvent e);
}
```

```
interface MouseMotionListener extends EventListener {
  public void mouseDragged(MouseEvent e);

  public void mouseMoved(MouseEvent e);
}
```