What To Turn In

Please hand in work in two pieces, one for the Problems and one for the Programming (Partner Optional):

Problems: Turn in handwritten or typed answers by the due date. Be sure your work is stapled and that your answers are clearly marked and in the correct order.

Programming (Partner Optional): This part involves writing Scala code. You are welcome to work with a partner but are not required to do so. I can also assist in matching pairs — simply send me email and I will pair you with someone else also looking for a partner. As usual please submit your code separate from the written answers and via turnin.

Reading

1. (Required) Mitchell, Chapter 12.
2. (Required) Mitchell, Chapter 13.
3. (As needed) Java and Scala Resources as needed for the programming.

Self Check

S1. .......................................................... Array Covariance in Java
   Mitchell, Problem 13.5

Problems

Q1. (10 points) .............................................. Subtyping and Exceptions
   Mitchell, Problem 13.3

Q2. (15 points) ......................... Java Interfaces and Multiple Inheritance
   In C++, a derived class may have multiple base classes. The designers of Java chose not to allow multiple inheritance. Therefore, a Java derived class may only have one base class. However, a Java class may be declared to implement more than one interface. This question asks you to compare these two language designs when consider the following kinds of movies:

   Movie: a class describing all kinds of movies
   Action: a movie containing lots of explosions
   Romance: a movie where romantic interest drives the plot
   Comedy: a movie with largely humorous content
   Mystery: a who-dunnit movie
**Rescue**: a hybrid action-romance movie, where the main character attempts to save his or her romantic interest from almost certain doom

**Romantic Comedy**: a hybrid romance-comedy with large amounts of both humorous and romantic content

**Hollywood Blockbuster**: an action-romance-comedy-mystery movie designed to please crowds

(a) Draw a C++ class hierarchy with multiple inheritance for the above set of classes.

(b) If you were to implement these classes in C++ for some kind of movie database, what kind of potential conflicts associated with multiple inheritance might you have to resolve?

(c) If you were to represent this hierarchy in Java, what interfaces and classes would you use? Write your answer by carefully drawing a class/interface hierarchy, identifying which nodes are classes and which are interfaces. Note that there must be a class for each of the movie genres, but you may use any interfaces you require to preserve the relationships between genres. For example, one way of doing this would be to have the Comedy and Romantic-Comedy genres both implement some kind of IComedy interface.

(d) Give an advantage of C++ multiple inheritance over Java classes and interfaces and one advantage of the Java design over C++.

(e) Assuming you will need to create objects of every movie type (other than Movie), do Scala traits offer a better solution in this case? Why or why not?

**Q3. (15 points) ........................................... Adding Pointers to Java**

Java does not have general pointer types. More specifically, Java only has primitive types (Booleans, integers, floating point numbers, . . . ) and reference types (objects and arrays). If a variable has a primitive type, then the variable is associated with a location, and a value of that type is stored in that location. When a variable of primitive type is assigned a new value, a new value is copied into the location. In contrast, variables of reference types are implemented as pointers. When a reference-type variable is assigned, Java copies a pointer to the appropriate object into the location associated with the variable.

Imagine that you were part of the Java design team and you believe strongly in pointers. You want to add pointers to Java, so that for every type A, there is a type A* of pointers to values of type A. Gosling is strongly opposed to adding an “address of” operator (like & in C), but you think there is a useful way of adding pointers without adding address-of.

One way of designing a pointer type for Java is to consider A* equivalent to the following class:

```java
class A* {
    private A data;

    A*() {
        data = null;
    }

    public void assign(A x) {
        data = x;
    }

    public A deref() {
        return data;
    }
}
```

Intuitively, a pointer is an object with two methods, one assigning a value to the pointer and the other dereferencing a pointer to get the object it points to. One pointer, p, can be assigned the object reached by another, q, by writing p.assign(q.deref()).
(a) If A is a reference type, do A* objects seem like pointers to you? More specifically, suppose A is a Java class with method m that has a side effect on the object. Consider the following code:

```
A x = new A(...);
A* p = new A*();
p.assign(x);
(p.deref()).m();
```

Here, pointer p points to the object named by x and p is used to invoke a method. Does this modify the object named by x? Answer in one or two sentences.

(b) What if A is a primitive type, such as int? Do A* objects seem like pointers to you? (Hint: Think about code similar to that in part (a).) Answer in one or two sentences.

(c) If A <: B, should A* <: B*? Answer this question by completing the following chart and explaining the relationship:

<table>
<thead>
<tr>
<th>Method</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>A*.assign</td>
<td>B*.assign</td>
</tr>
<tr>
<td>A*.deref</td>
<td>B*.deref</td>
</tr>
</tbody>
</table>

(d) Can you generalize the issue discussed in part (c) to Java generics? More specifically, What might happen if you had a pointer generic? Based on the Ptr example, do you think it is correct to assume that for every generic class T, if A <: B then T<A> <: T<B>? Explain briefly.

**Q4.** (12 points) ..............................  Upper and Lower Bounds on Types

Type parameters in Scala (and Java) can be given upper and lower bounds to restrict how they can be instantiated. Specifically, the type List[_ <: C] describes a list that stores some data of some type that is a subtype of class C. In other words, the type parameter has an upper bound C. For example, an object of List[_ <: Point] is a list that contains objects which extend the Point class. For example, the list could be List[Point] or List[ColorPoint], etc. Reading an element from such a list is guaranteed to return a Point, but writing to the list is not generally allowed. This sort of bounded type is often called an existential type because it can be interpreted as “there exists some type T such that T <: C.”

Existential types can also have lower bound constraints. A constraint [_ >: C] means that the existential type must be a supertype of class C. For example, an object of List[_ >: Point] could be a List[Point] or List[Any]. (Any is the supertype of all types in Scala, and serves similar purposes as Object in Java). Reading from such a list returns objects of type Any, but any object of type Point can be added to the list.

This question asks about generic versions of a simple function that reads elements from one list and adds them to another. Here is sample non-generic code, in case this is useful reference in looking at the generic code below.

```
def addAllNonGeneric(src: MutableList, dest: MutableList) : Unit = {
  for (o <- src) {
    dest += o;
  }
}
val listOfPoints = new MutableList();
val listOfColorPoints = new MutableList();
...
addAllNonGeneric(listOfColorPoints, listOfPoints);
```
It will not compile in Scala, but gives you an idea of what we're trying to do.

(a) The simplest generic version of the `addAll` method uses an unconstrained type parameter and no bounds.

```scala
def addAll0[T](src: MutableList[T], dest: MutableList[T]) : Unit = {
  for (o <- src) {
    dest += o;
  }
}
```

Suppose that we declare

```scala
val listOfPoints : MutableList[Point] = new MutableList[Point]();
val listOfColorPoints : MutableList[ColorPoint] = new MutableList[ColorPoint]();
```

and call

```scala
addAll0(listOfColorPoints, listOfPoints).
```

Will this call compile or will a type error be reported at compile time? Explain briefly.

(b) With `listOfColorPoints` and `listOfPoints` defined as in the previous part of this question, will the call

```scala
addAll1(listOfColorPoints, listOfPoints)
```

compile, where `addAll1` is defined as follows:

```scala
def addAll1[T](src: MutableList[<: T], dest: MutableList[T]) : Unit = {
  for (o <- src) {
    dest += o;
  }
}
```

Explain briefly.

(c) With `listOfColorPoints` and `listOfPoints` defined as in the previous part of this question, will the call

```scala
addAll2[ColorPoint](listOfColorPoints, listOfPoints)
```

compile, where `addAll2` is defined as follows:

```scala
def addAll2[T](src: MutableList[T], dest: MutableList[>: T]) : Unit = {
  for (o <- src) {
    dest += o;
  }
}
```

Explain briefly. (The explicit instantiation of `T` in the call to `addAll2` is needed because of how Scala infers types.)

(d) Suppose that your friend comes across the following general programming suggestion on the web and asks you to explain. What can you tell your friend to explain the connection between the programming advice and principles of subtyping, showing off your understanding gained from CS 334?

**Get and Put Principle:** If you pass a generic structure to a function:

- Use an existential type with an upper bound (ie, `[_: T]`) when you only GET values out of the structure.
- Use an existential type with a lower bound (ie, `[>: T]`) when you only PUT values into the structure.
- Don't use an existential type when you both GET and PUT values out of / into the structure.
Q5. (20 points) Template Expansion versus Type Erasure

Java and C# implement generics in two different ways. Java generics are implemented using an erasure technique discussed in class that inserts casts and uses one run-time copy of the code for all instantiations of the generic. Although C# is similar to Java in some respects, the C# implementation of generics may produce separate copies if several instances of a generic are used in a program. The C# implementation has some general similarities to the C++ implementation of templates.

(a) Java chose the erasure and cast implementation of generics for several reasons. One was the large number of users running old Java VMs and a huge amount of legacy code. Why does the type erasure and casts implementation support both legacy code and old VMs better than an implementation that uses expansion.

(b) You are sitting in Tunnel City Coffee and overhear a conversation between Rocky and Bullwinkle. Rocky says:

“I think C# made the wrong choice when adding generics to their language: they’ve invalidated all their old code and VMs. Java does it right.”

Bullwinkle replies:

“But what if your old code starts adding Strings onto your Vector<Integer>? This is wrong, but the error is not detected until you use the inserted String. It should be detected when the old code inserts a String into a Vector<Integer>.”

Using that fact that Vector<Integer> <: Vector, write a short program that exhibits the problem Bullwinkle describes.

(c) Rocky replies:

“I have a solution to this problem. I just use this special MyVector:

```java
class MyVector<T> extends Vector {
    void add (Object a) {
        try {
            T tmp = (T)a;
            super.add(tmp);
        } catch (ClassCastException c) {
            System.out.println("Error Detected");
        }
    }
}
```

It will catch errors at run time right when a program tries to add a String into a Vector<Integer>, instead of waiting until the String is used as an int.

Bullwinkle rolls his eyes and tells Rocky that his scheme would never detect those insertion errors when they happen, even at run time. Who is right? Explain why.

(d) Sometimes Java’s use of erasure and casting has very bizarre effects. In this case, write the console output of the following program.

```java
class Container<T> {
    public T internal;
    public static Container lastInstance;
    Container(T value){
        internal = value;
        lastInstance = this;
    }
}
class Main {
```
public static void main(String args[]) {
    Container<String> str = new Container<String>("Cow");
    Container<Integer> myint = new Container<Integer>(31337);
    System.out.println("Last Instance: " + str.lastInstance.internal);
}

Explain why it behaves this way in terms of generics and Java erasure.

(ε) C++ uses the expansion method for its templates instead of Erasure and inserted casts. What does the output of the same program translated into C++ look like. Write the output and explain why it is different or why it remains similar even with a different template expansion mechanism.

(f) It is sometimes useful to create “mixins.” A mixin class is a class that inherits from a template parameter like so:

```java
class MyClass <T> extends T {
    ...
}
```

Why is this construct ineffective when used with erasure and casting?

---

P1. (40 points) ................................. Undoable Commands

The goal of this problem is to implement the core data structures of a text editor using the Command Design Pattern.

**Text Editor**  In essence, a text editor manages a character sequence that can be changed in response to commands issued by the user, such as inserting new text or deleting text. Typically, these commands operate on the underlying character buffer at the current position of the cursor. Thus, if the cursor is positioned at the beginning of the buffer, typing the string “moo” will cause those letters to be inserted at the start of the buffer, and so on. This question explores the internal design of a simple editor.

Most text editors involve a GUI and the user issues commands to the editor by keyboard and mouse events. For us, however, the most interesting part of a text editor’s is what happens behind the scenes. Therefore, our text editor will just be a simple command line program that prompts you for edit commands. The program will print the contents of the text editor’s buffer, including a “^” to indicate the current cursor position, print the prompt “?”, and then wait for you to enter a command. At one point in time, this was in fact how many text editors worked — look up “ed text editor” in Wikipedia, for example (or run it on our lab machines...). The following shows one run of our editor:
Sample Execution

<table>
<thead>
<tr>
<th>Buffer:</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>^</code></td>
<td>Insert “This is a test.” and move cursor to immediately after inserted text</td>
</tr>
<tr>
<td><code>^</code></td>
<td>Move cursor 9 characters left</td>
</tr>
<tr>
<td><code>^</code></td>
<td>Move cursor 1 character right</td>
</tr>
<tr>
<td><code>^</code></td>
<td>Insert “n’t”</td>
</tr>
<tr>
<td><code>^</code></td>
<td>Move cursor 3 characters right</td>
</tr>
<tr>
<td><code>^</code></td>
<td>Delete 4 characters.</td>
</tr>
<tr>
<td><code>^</code></td>
<td>Insert “cow”</td>
</tr>
<tr>
<td><code>^</code></td>
<td>Quit</td>
</tr>
</tbody>
</table>

Here is a summary of all available editor commands (including some described below). The term \([num]\) indicates an optional number.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I text</td>
<td>Insert text at the current cursor, moving cursor to after the new text.</td>
</tr>
<tr>
<td>D [num]</td>
<td>Delete num characters to the right of cursor position. (If num is missing, delete 1 character.)</td>
</tr>
<tr>
<td>&lt; [num]</td>
<td>Move the cursor num characters to the left. (If num is missing, move 1 character.)</td>
</tr>
<tr>
<td>&gt; [num]</td>
<td>Move the cursor num characters to the right. (If num is missing, move 1 character.)</td>
</tr>
<tr>
<td>Q</td>
<td>Quit</td>
</tr>
<tr>
<td>U</td>
<td>Undo the previous edit command</td>
</tr>
<tr>
<td>P</td>
<td>Print the history of edit commands</td>
</tr>
<tr>
<td>R</td>
<td>Redo an undone edit command</td>
</tr>
</tbody>
</table>

I have provided a working program for all but the last three commands. Your job is to change TextEditor to support multiple levels of undo and redo using the Command Design Pattern.

Figure [I] shows an example that uses “U” (undo) and “P” (print history). (We’ll look at “R” (redo) at the very end of the problem.) Notice that you can undo multiple edits, not simply the last one. To support this, the text editor must keep track of an edit command history that permits you to undo as many commands from the history as you like. Undoing all commands will lead you all the way back to the original empty buffer.

The starter code for this problem is divided into two classes:

- Buffer: This class manages the internal state of the editor's buffer (ie, character sequence and current cursor location), and it supports commands for getting/setting the cursor location and for inserting/deleting text. Refer to the javadoc on the handouts page for more details. You should not change this class.
Sample Execution | Description
---|---
Buffer:  |  
? I Hello  
Buffer: Hello  
? < 2  
Buffer: Hello  
? D 2  
Buffer: Hel  
? I p  
Buffer: Help  
? U  
Buffer: Hel  
? I ium  
Buffer: Helium  
? P  
Print the command history.
History:  
[Insert "Hello"]  
[Move to 3]  
[Delete 2]  
[Insert "ium"]  
Buffer: Helium  
? U  
Undo the previous command.
Buffer: Hel  
? U  
Undo the last command ([Insert "ium"]).
Buffer: Hel  
? U  
Undo the last command ([Delete 2]).
Buffer: Hello  
? P  
Print the command history.
History:  
[Insert "Hello"]  
[Move to 3]  
Buffer: Hello  
? Q  

Figure 1: Sample run of the text editor with undo.
TextEditor: This class stores a Buffer named buffer. The processOneCommand() method reads in a command from the user and performs the appropriate operation on buffer by invoking one of the following methods:

- protected def setCursor(loc: Int): Unit
- protected def insert(text: String): Unit
- protected def delete(count: Int): Unit
- protected def undo(): Unit
- protected def redo(): Unit
- protected def printHistory(): Unit

These methods are all quite simple. For example, the insert method simply inserts the text into buffer and repositions the cursor:

```scala
protected def insert(text: String) = {
  buffer.insert(text);
  buffer.setCursor(buffer.getCursor() + text.length());
}
```

The EditCommand Class To support undo, we first change the way the TextEditor operates on the underlying buffer. Rather than changing it directly, the TextEditor constructs EditCommand objects that know how to perform the desired operations and — more importantly — know how to undo those operations. All EditCommand objects will be derived from the EditCommand abstract class:

```scala
abstract class EditCommand(val target: Buffer) {
  /** Perform the command on the target buffer */
  def execute(): Unit;

  /** Undo the command on the target buffer */
  def undo(): Unit;

  /** Print out what this command represents */
  def toString(): String;
}
```

Here, the execute() method carries out the desired operation on the target buffer, and undo() would perform the inverse operation. For example, to make insert undoable, the first step would be to define an InsertCommand class in a new file InsertCommand.scala:

```scala
class InsertCommand(b: Buffer, val text: String) extends EditCommand(b) {
  override def execute(): Unit = { ... }
  override def undo(): Unit = { ... }
  override def toString(): String = { ... }
}
```

The TextEditor would then perform code like the following inside insert:

```scala
protected def insert(text: String) = {
  val command = new InsertCommand(buffer, text);
  command.execute();
  ...
}
```
Assuming InsertCommand is implemented properly, the insertion would happen as before. However, the TextEditor can now remember that the last operation performed was the InsertCommand we created, and we can undo it simply by calling that object's undo() method. In essence, an EditCommand object describes one modification to a Buffer's state and how to undo that modification. Supporting undo is then as simple as writing a new kind of EditCommand object for each type of buffer modification you support.

And of course, to implement multiple levels of undo, you need to keep track of more than just the last command object created...

**Implementation Strategy**  I suggest tackling the implementation the following steps:

(a) Download the starter code from the handouts page. Compile the Scala files with the command `fsc *.scala` as usual. I have added some assert statements to the Buffer class to aid in debugging. The general form is

```
assert(condition, { "message" })
```

You may find it useful to add similar asserts to your own code as well.

(b) Implement InsertCommand, DeleteCommand, and MoveCommand subclasses of EditCommand. For each one, you must define: 1) execute(), 2) undo(), and 3) toString(). I recommend holding off on undo() for the moment. Change TextEditor to create and execute edit command objects appropriately.

(c) Extend TextEditor to remember the last command executed, and change TextEditor's undo() method to undo that command. Go back and implement undo for each type of EditCommand.

(d) Once a single level of undo is working, extend TextEditor to support undoing multiple previous commands. Specifically, change TextEditor to maintain a history of commands that have been executed and not undone. Also implement the printHistory() method to aid in debugging. Your program should simply ignore undo requests if there are no commands are in the history. You are free to use any Scala libraries you like in your implementation (ie, any immutable or mutable collection class).

(e) The last task is to implement redo. Specifically, if you undo one or more commands but have not yet performed any new operations on the buffer, you can redo the commands you undid:
Note that redoing undone commands is no longer possible if the buffer is changed in any way. For example, if you insert text after undoing some command $E$, you should no longer be able to redo command $E$:
Sample Execution Description

Buffer:  
?
Buffer: 334
?
Buffer: 334cow
?
Buffer: 334cowmoo
?
Buffer: 334cow
?
Buffer: 334
?
Buffer: cow
?
Buffer: moo
?
Buffer: 334cowmoo
?
Buffer: 334cow
?
Buffer: 334
?
Buffer: cow
?
Buffer: moo
?
Buffer: 334cowmoo
?
Buffer: 334cow
?
Buffer: 334
?
Buffer: cow
?
Buffer: 334cowmoo
?
Buffer: 334cowmoo
?
Buffer: 334cow
?
Buffer: 334
?
Buffer: cow
?
Buffer: 334
?
Buffer: 334cowmoo
?
Buffer: 334cow
?
Buffer: 334cowmoo
?
Buffer: 334cow
?
Buffer:

Extend TextEditor to support multiple levels of redo. You should not need to change any class other than TextEditor to implement this feature.

There are many extensions that would make our editor more “realistic”. One idea is listed below as an extra credit problem. It should not require more than a few additional lines of code and really highlights the elegance and simplicity of adopting this design pattern.

P2. (15 points) .................... (Bonus Question) Composable Commands

Here is one interesting extension to the basic Text Editor. (No need to hand in a separate version of the code for this part if you choose to work on it – simply change your solution to P1. But be sure to commit your earlier version in case you wish to revert back to it!)

Most of the time, two consecutive commands of the same type are lumped together into a single command. Thus, if I type “hello” followed immediately by “there” into an editor (such as emacs), the editor lumps them together into a single insertion command that removes all of “hello there”
from the buffer when undone. Similarly, if I perform two cursor movement commands in a row, that is recorded in the undo history as a single command. Here is an example:

<table>
<thead>
<tr>
<th>Sample Execution</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffer:</td>
<td></td>
</tr>
<tr>
<td>^</td>
<td></td>
</tr>
<tr>
<td>? I hel</td>
<td></td>
</tr>
<tr>
<td>Buffer: hel</td>
<td></td>
</tr>
<tr>
<td>? I ium</td>
<td>second insert composed with first</td>
</tr>
<tr>
<td>Buffer: helium</td>
<td></td>
</tr>
<tr>
<td>? P</td>
<td></td>
</tr>
<tr>
<td>History:</td>
<td>[Insert “helium”]</td>
</tr>
<tr>
<td>Buffer: helium</td>
<td></td>
</tr>
<tr>
<td>? U</td>
<td></td>
</tr>
<tr>
<td>Buffer:</td>
<td></td>
</tr>
<tr>
<td>? R</td>
<td></td>
</tr>
<tr>
<td>Buffer: helium</td>
<td></td>
</tr>
<tr>
<td>? &lt;</td>
<td></td>
</tr>
<tr>
<td>Buffer: helium</td>
<td></td>
</tr>
<tr>
<td>? &lt; 2</td>
<td>second move composed with first</td>
</tr>
<tr>
<td>Buffer: helium</td>
<td></td>
</tr>
<tr>
<td>? D 2</td>
<td></td>
</tr>
<tr>
<td>Buffer: helm</td>
<td></td>
</tr>
<tr>
<td>? D 1</td>
<td>second delete composed with first</td>
</tr>
<tr>
<td>Buffer: hel</td>
<td></td>
</tr>
<tr>
<td>? P</td>
<td></td>
</tr>
<tr>
<td>History:</td>
<td>[Insert “helium”]</td>
</tr>
<tr>
<td>[Move to 3]</td>
<td>[Delete 3]</td>
</tr>
<tr>
<td>Buffer: hel</td>
<td></td>
</tr>
<tr>
<td>? I p</td>
<td>undo insert of “p”</td>
</tr>
<tr>
<td>Buffer: help</td>
<td></td>
</tr>
<tr>
<td>? U</td>
<td>undo composed delete command</td>
</tr>
<tr>
<td>Buffer: helium</td>
<td></td>
</tr>
<tr>
<td>? U</td>
<td>undo composed move command</td>
</tr>
<tr>
<td>Buffer: helium</td>
<td></td>
</tr>
<tr>
<td>? U</td>
<td>undo composed insert of “helium”</td>
</tr>
<tr>
<td>Buffer:</td>
<td></td>
</tr>
</tbody>
</table>

Implement composable commands. A good way to start is to extend the EditCommand class and its
subclasses to define the following method:

    def compose(other : EditCommand) : Option[EditCommand]

This method either:

- returns None if the current command cannot be composed with other.
- returns a new command if the current command can be composed with other, because, for example, they are both insert commands.

For example,

```scala
val c1 = new InsertCommand(target, "hel");
val c2 = new InsertCommand(target, "lo");
c1.compose(c2) match {
    case None => // can’t combine them
    case Some(c3) => c3.execute();
}
```

would create the command \(c_3\) that inserts “hello” into the target. If we changed \(c_2\) to be a DeleteCommand, the \(\text{compose}\) operation would return None. You may find it useful to test whether an object has a certain type, which can be done in Scala with pattern matching, as in:

```scala
x match {
    case i : InsertCommand => ... // x is an InsertCommand, now bound to i
    case i : DeleteCommand => ... // x is an DeleteCommand, now bound to i
    case i => ... // match all other types
}
```

**What To Turn In for the Programs.**

- Your code for the programming questions should be documented, and include your ID (and that of your partner) at the top of each file.

- Turn in a printout of your code file *separate* from the answers to the written problems. If you worked with a partner, please turn in only one copy.

- Also, commit and push all of your code to our Gitlab server.