

Problem Set 2

Due: 6pm Tuesday, February 17

Due Date:

Because this assignment was posted late, its due date has been extended from Fri. Feb. 13 to Tue. Feb 17. However, you are encouraged to complete as much of the assignment as possible before Fri. Feb 13 since most help from instructors and tutors will be available between Tue. Feb 10 and Fri. Feb. 13. This will also give you more time to enjoy the long weekend.

Overview:

The purpose of this assignment is to give you practice with Java arrays, vectors, and loops (including nested loops). You will also get some practice with writing your own test cases and writing a class from scratch.

Reading:

- Read Chapters 10–12 of Downey’s online Java book (accessible from the Resource Links section of the CS230 home page).

Submission:

Each team should turn in a single hardcopy submission packet for all problems by slipping it under Lyn’s office door by 6pm on the due date. The packet should include:

1. a team header sheet (see the end of this assignment for the header sheet) indicating the time that you (and your partner, if you are working with one) spent on the parts of the assignment.
2. your final version of `SetTableau.java` from Problems 1 and 2.
3. a transcript of your tests from Problem 2.
4. your final version of `SetGameHistogram.java` from Problem 3.
5. a transcript of your histograms from Problem 3.

Each team should also submit a single softcopy (consisting of your final `ps2` directory) to the drop directory `~cs230/drop/ps2/username`, where `username` is the username of one of the team members (indicate which drop folder you used on your hardcopy header sheet). To do this, execute the following commands in Linux in the account of the team member being used to store the code.

```
cd /students/username/cs230
cp -R ps2 ~cs230/drop/ps2/username/
```

Problem 0: The Game of Set

In this assignment, you will use the `SetCard` and `SetHand` classes you worked with in PS1 to implement a simple version of the Game of Set. Before starting the assignment, you should familiarize yourself with the rules of the game and some other classes by reading the rest of this problem.

a. : The Rules of CS230 Set

In this assignment, we will play a variant of the Game of Set that is somewhat simpler than the real game.¹ We will call our variant CS230 Set. Although the usual Game of Set has any number of players, CS230 Set will have only one player. Our variant is thus a kind of solitaire.

CS230 Set is played with a deck of the 81 possible Set cards. The game starts by dealing some number of these cards face up to form what is called the **tableau**. The size of the tableau remains constant as long as there are still cards left in the deck, but may shrink after the deck is empty. The game can be played with any size of tableau, but 12 cards is the default.

At each step of the game, the player tries to find three cards in the tableau that form a set. Sometimes there may not be any sets in the tableau, so the player is allowed to declare that there are no sets in the tableau. We have the following cases:

- If the player selects three cards that form a set, the player “wins” the hand consisting of the three cards. These three cards are removed from the tableau. If the deck has three or more cards, three cards are dealt from the deck to replace the three taken by the player. If the deck has fewer than three cards, all remaining cards from the deck (if any) are added to the tableau.
- If the player selects three cards from the tableau that do not form a set, the game ends.
- If the player declares that there are no sets in the tableau, the game ends, regardless of whether the declaration is true or not. In the case where the player is incorrect, the player is penalized by not being able to continue the game to win more hands. In the case where the player is correct, the game ends because there are no more sets.²

When the game ends, how well the player did is measured by the total number of sets the player won. This number may range between 0 (no hands won) to 27 (the maximum number of winnable sets). In CS230 Set, this number is determined by both luck and skill – luck, because a set-less tableau can end a game early; and skill, because the player advances by finding a set in a tableau that has one.

b. : The Contracts

In addition to the `SetCard` and `SetHand` contracts from PS1, the implementation of CS230 Set involves contracts for three new classes:

1. The `SetTableau` class represents a tableau of Set cards. See Appendix A for the contract for this class. This is the class that you will implement in Problems 1 and 2.
2. The `SetDeck` class represents a deck of Set cards. See Appendix B for the contract for this class.

¹For more about the real game, see <http://www.setgame.com/set/>.

²In the real version of the game, when a player correctly declares that there are no more sets, the size of the tableau is increased (if possible) by dealing three more cards from the deck.

- The `SetGame` class represents a CS230 Set game. See Appendix C for the contract for this class.

You should study all three of the above contracts before proceeding.

c. : Game Modes

There are two modes in which the CS230 Set game can be played.

- In **automatic mode**, a computer player automatically plays the game. Using the `leastSet` method of the `SetTableau` class, the computer player chooses the least set from the current tableau (if there is one) at every step of the game. This continues until the tableau contains no more sets. Fig. 2 shows a transcript of a sample automatic game.

```
[lyn@jaguar ps2] java SetGame automatic 12 true
-----
1hgc      2ebt      2hbs      2hbt
2hgc      2hrs      2hrt      3fbt
3fgs      3frt      3hgc      3hrt

Found set [1hgc,2hbs,3hrt]
Automatic player has 1 sets
-----
1fbs      2ebt      2egc      2hbt
2hgc      2hrs      2hrt      3fbt
3fgs      3frs      3frt      3hgc

Found set [2hbt,2hgc,2hrs]
Automatic player has 2 sets
-----
1egc      1fbs      2ebt      2egc
2hrt      3egc      3fbs      3fbt
3fgs      3frs      3frt      3hgc

Found set [1egc,2egc,3egc]
Automatic player has 3 sets
-----
1fbs      1fbt      2ebt      2hrt
3ebt      3fbs      3fbt      3fgs
3frs      3frt      3hgc      3hrc

Found set [3ebt,3fgs,3hrc]
Automatic player has 4 sets
-----
1ebt      1fbs      1fbt      1frc
1hrc      2ebt      2hrt      3fbs
3fbt      3frs      3frt      3hgc

There are no more sets.
Automatic player won 4 sets:
[1hgc,2hbs,3hrt],[2hbt,2hgc,2hrs],[1egc,2egc,3egc],[3ebt,3fgs,3hrc]
```

Figure 1: Transcript of a sample automatic 12-card game. In this game, the automatic player wins only 4 sets.

2. In **interactive mode**, the user plays the game. At each step of the game, the user can enter one of four inputs:
 - (a) A string representation of a Set hand (e.g., `[1fbt,2fgc,3frs]`) that specifies a set in the tableau.
 - i. if the hand is a set in the tableau, the player wins this hand;
 - ii. if the hand is in the tableau, but is not a set, the game ends;
 - iii. if the hand string is ill-formed or not all of the cards are in the tableau, the input is assumed to be a mistake, and the player is given another chance to give an input.
 - (b) The input `none` is used to declare that there are no sets in the tableau. As explained above, this ends the game.
 - (c) The input `done` ends the game when the player does not wish to continue.
 - (d) The input `help` displays instructions for playing the game.

Fig. 2 shows a transcript of a short game played in interactive mode.

d. : Implementations

You have been provided with implementations of the `SetDeck` and `SetGame` classes in the files `ps2/SetDeck.java` and `ps2/SetGame.java`. You are encouraged to study these implementations before you proceed with the implementation of `SetTableau` in Problems 1 and 2. There are two reasons to study the implementations:

1. They include some programming idioms that are handy to know. In particular, they include array, vector, and loop idioms that may be useful to you for implementing `SetTableau`.
2. A better understanding for the structure of the game and how the `SetTableau` class is used within the game may help you in your implementation.

```

[lyn@jaguar ps2] java SetGame interactive 12
Welcome to the CS230 Set Game!

When a Set tableau is displayed, you have the following options:
1. Type in a set appearing in the tableau -- e.g. [1ebc,2fgs,3hrt].
   * If the hand is a set in the tableau, you win it;
   * If the hand is in the tableau, but not a set, the game ends;
   * If the hand is illegal or not in the tableau,
     you will be given a chance to type in another set.
2. Type "none" (without the quotes) if you think there are no sets in the tableau.
   This ends the game whether you are right or wrong.
3. Type "done" (without the quotes) if you want to exit the game.
4. Type "help" (without the quotes) to see these instructions.
-----
1ebs      1fbs      1fgt      1frc
2fgc      2hrs      3egs      3fbc
3fbt      3frs      3hgs      3hrs

Type a set hand representation, "done", "none", or "help" (w/o quotes):
[1fbs,1fgt,1frc]
Good! You now have 1 sets
-----
1ebc      1ebs      1ers      2ebs
2fgc      2hrs      3egs      3fbc
3fbt      3frs      3hgs      3hrs

Type a set hand representation, "done", "none", or "help" (w/o quotes):
[1ers,2ebs,3egs]
Good! You now have 2 sets
-----
1ebc      1ebs      1fbt      2egt
2fgc      2hgc      2hrs      3fbc
3fbt      3frs      3hgs      3hrs

Type a set hand representation, "done", "none", or "help" (w/o quotes):
none
Nope -- you missed the following sets:
[1fbt,2fgc,3frs]

Thanks for playing the CS230 Set Game!
You won 2 sets:
[[1fbs,1fgt,1frc], [1ers,2ebs,3egs]]

```

Figure 2: Transcript of a sample automatic 12-card game. In this game, the automatic player wins only 4 sets.

Problem 1 [65]: Implementing SetTableau

Flesh out the skeleton implementation of the `SetTableau` class in `ps2/SetTableau.java` so that it satisfies the contract in Appendix A. This class contains a single private instance variable named `cards` that holds a vector of the cards in the tableau. In your implementation, you should maintain the invariant that the cards in `cards` are always stored in sorted card order from least to greatest. This simplifies the implementation of the `cards`, `toString`, `tableString`, `sets`, and `leastSet` methods.

Notes:

- To begin this problem, execute the following in Linux:

```
cd ~/cs230
cvs update -d
```

- To compile your class, use `javac SetTableau.java`.
- Although Problem 1 and Problem 2 are listed as separate problems, you will probably want to interleave them.
- Use `VectorOps.isort` to sort a vector of `SetCards` or a vector of `SetHands`. (This sorts any vector of `Comparable` objects.)
- The `VectorOps.binarySearch` method introduced in class is an easy way to find the index or insertion index of an element in a sorted vector. This method is handy in several of the `SetTableau` methods.
- Do not use the `contains(Object elem)` or `remove(Object elem)` methods of the `Vector` class. But you may use the `remove(int index)` method.
- In `tableString`, the `Math.sqrt` and `Math.ceil` functions are handy. Note that `Math.ceil` takes a `double` and returns a `double`. You should use an `(int)` cast to convert it to an integer. To get a `double` result from dividing two integers, you first need to cast one of the integers to a `double` using `(double)`. For instance, in Java, $7/2$ is 3, but `((double) 7)/2`, `7/((double)2)`, and `((double)7)/((double)2)` all return 3.5.
- The hardest methods to implement are `sets` and `leastSet`. The most straightforward implementation involves a triply nested loop with indices `i`, `j`, and `k` such that $i < j < k$. Think carefully about these problems before you implement them.
- Your `leastSet` method should *not* invoke `sets` and extract the smallest element of the result. Although it's often a good idea to implement one method in terms of another, the key idea behind `leastSet` is that it should be cheaper than `sets` because it only finds one set rather than all of them. Implementing `leastSet` in terms of `sets` would violate this expectation.

It is likely that your `leastSet` method will look very much like your `sets` method except for a few tweaks. This should cause some queasiness – after all, shouldn't we abstract over common code patterns? Yes, but not yet in this case. Soon we will learn about an abstraction (called an `Enumeration`) that is the right way to abstract over the commonalities between `leastSet` and `sets`.
- The `Vector toArray` method is helpful for returning a `SetCard` array in `cards` and `SetHand` array in `sets`. See examples of its use in `SetGame.java`.

- Once you have successfully implemented `SetTableau`, you should be able to compile `SetGame` (via `javac SetGame.java`). Then you can play CS230 Set — in automatic or interactive mode — as described in Appendix C.

Problem 2 [15]: Testing `SetTableau`

Add a `main` method and testing code to the `SetTableau` class to test your implementation from Problem 1. You needn't implement anything as fancy as the testing code in PS1, though you are welcome to do so if you like. At the very least, you should have a way of testing each of your methods by giving appropriate arguments to `main`.

For this problem you should turn in a transcript of the tests that you perform. The easiest way to generate a transcript is to perform all of your tests within a shell buffer inside Emacs, and then save this buffer away to a file.

Problem 3 [20]: Game Histograms

How does the size of the tableau influence the number of sets that are typically collected in a CS230 Set game? Intuitively, it's hard to find sets in small tableaux, so few sets will be collected when the tableau size is small. As the tableau size increases, we expect the the number of sets collected in a typical game will rise.

In this problem, you will investigate how the distribution of the number of sets collected in the CS230 Set Game depends on the size of the tableau. You will do this by writing a program that makes a **histogram** of the number of sets collected in each of t trials of an automatic game with a tableau of size n . A histogram is a table with indexed slots. Here, the indices range from 0 (the smallest number of sets that can be won in a game) up to and including 27 (the largest number of sets that can be won in a game). The histogram stores in index slot i the number of games out of the t trials in which exactly i sets were won.

For example, Fig. 3 shows a sample histogram for 100 trials of a game using a tableau size of 10. The first line of the histogram says that in 14 of the 100 games played, no sets were won in the game; the second says that exactly one game was one in 13 of the 100 games; and so on. The total number of games in the histogram is 100.

In this problem, you should write, from scratch, a class named `SetGameHistogram` in a file named `ps2/SetGameHistogram.java`. The `main` method of this class should produce histograms like the one in Fig. 3. Your class should have as many methods as you need to solve the problem.

You should test your class by computing histograms for all tableau sizes n between 9 and 15, inclusive. In each histogram, use 100 trials. Note that as n grows larger, the time to compute the histogram grows larger as well; be patient. For example, on my laptop, computing the histogram for $n = 15$ and $t = 100$ takes about a minute. (Yours may take more or less time, depending on the machine you are using and the efficiency of your `SetTableau` implementation.) Turn in a transcript showing your histograms.

Also, answer this question: based on your histogram results, what do you think is the most sensible default size for a game of CS230 Set? There is no right or wrong answer here — I want to hear your reasoning!

Notes:

- You should use the `automatic` method of the `SetGame` class to play each game. Using the `verbose` flag `false` will prevent the details of each game from being displayed on the screen.
- It does not take very much code to solve this problem. It is possible to solve it using one or two short methods, though you are welcome to use more.

```
[lyn@jaguar ps2] java SetGameHistogram 10 100
0 sets: 14
1 sets: 13
2 sets: 14
3 sets: 10
4 sets: 9
5 sets: 5
6 sets: 6
7 sets: 5
8 sets: 5
9 sets: 5
10 sets: 5
11 sets: 2
12 sets: 1
13 sets: 0
14 sets: 2
15 sets: 0
16 sets: 1
17 sets: 1
18 sets: 1
19 sets: 0
20 sets: 0
21 sets: 0
22 sets: 0
23 sets: 1
24 sets: 0
25 sets: 0
26 sets: 0
27 sets: 0
```

Figure 3: Sample histogram of 100 trials for a game with tableau size 10.

Going Further

You are encouraged to explore improvements and extensions to the game presented in this assignment. There are many ways to improve the CS230 Set Game. The text-based interface is very clunky and could be made more user-friendly. A graphical user interface (GUI) would be even nicer. (You will learn how to implement GUIs later in the semester.) The rules of the game could be modified to be more like those in the real Game of Set. For example, the real game involves multiple players, and the tableau size is increased (if possible) when all players agree that the tableau contains no sets.

Appendix A: SetTableau Contract

The `SetTableau` class models the collection of cards face up on the table in the Game of Set.

Public Constructor Methods:

```
public SetTableau ();
```

Creates a tableau with 0 cards.

```
public SetTableau (String [] cardStrings);
```

Creates a tableau whose cards are determined by the string representations of cards in `cardStrings`. Throws a `RuntimeException` if any of the strings are not legal card representations or if the same card appears more than once in `cardStrings`.

```
public SetTableau (SetCard [] scards);
```

Creates a tableau whose cards are the cards in `scards`. Throws a `RuntimeException` if the same card appears more than once in `scards`.

Public Instance Methods:

```
public int size ();
```

Returns the number of cards in this tableau.

```
public SetCard [] cards ();
```

Returns all the cards of this tableau in an array. In the resulting array, the cards should be sorted from least to greatest in the card ordering.

```
public void add (SetCard sc);
```

Adds `sc` to this tableau. Throws a `RuntimeException` if `sc` is already in the tableau.

```
public boolean contains (SetCard sc);
```

Returns `true` if `sc` is in this tableau and `false` otherwise.

```
public boolean contains (SetHand sh);
```

Returns `true` if all the cards in `sh` are in this tableau and `false` otherwise.

```
public void remove (SetHand sh);
```

If `sh` is a set, removes the three cards in `sh` from this tableau. Throws a `RuntimeException` if `sh` is not a set or the hand is not contained in this tableau.

```
public String toString ();
```

Returns a string representation of the cards in this tableau. This should be a comma-separated sequence of card strings (in sorted order from least to greatest) delimited by squiggly brackets. For example, here is the string representation of a 12-card tableau we'll call `sample`:

```
{1ebc,1erc,1fbc,1fbt,1hbc,1hbs,1hrs,2erc,2fgc,3fgt,3frs,3erc}
```

```
public String tableString ();
```

Returns a string representing the cards of this tableau as newline-separated rows of tab-separated columns of card strings. If n is the number of cards in this tableau, then the number of columns c should be $\lceil \sqrt{n} \rceil$ and the number of rows r should be $\lceil n/c \rceil$ (where n/c is mathematical division on real numbers, not Java's `/` operator).³ The cards should be shown in card order from least to greatest. For example, Fig. 4 shows the result of displaying tableaux with 9 through 13 cards.

```
// 9-card tableau
1ebc  1erc  1fbc
1fbt  1hbc  1hbs
1hrs  2erc  2fgc

// 10-card tableau
1ebc  1erc  1fbc  1fbt
1hbc  1hbs  1hrs  2erc
2fgc  3fgt

// 11-card tableau
1ebc  1erc  1fbc  1fbt
1hbc  1hbs  1hrs  2erc
2fgc  3fgt  3frs

// 12-card tableau
1ebc  1erc  1fbc  1fbt
1hbc  1hbs  1hrs  2erc
2fgc  3fgt  3frs  3erc

// 13-card tableau
1ebc  1erc  1fbc  1fbt
1hbc  1hbs  1hrs  2erc
2fgc  3fgt  3frs  3erc
3hrt
```

Figure 4: Results of calling the `tableString` method with tableaux ranging in size from 9 to 13.

```
public SetHand [] sets ();
```

Returns an array of all sets in this tableau. The sets in the returned array should be ordered from least to greatest according to the `SetHand` ordering. For example, for the 12-card `sample` tableau introduced in the `toString` specification, `sets()` should return an array of 6 hands:

```
{ [1ebc, 1fbc, 1hbc], [1ebc, 1fbt, 1hbs], [1erc, 2erc, 3erc],
  [1fbt, 2fgc, 3frs], [1hbc, 2fgc, 3erc], [1hbs, 2erc, 3fgt] }
```

```
public SetHand leastSet ();
```

Returns the least set (by the `SetHand` ordering) in this tableau if there is one. Otherwise returns `null`. For example, for the 12-card `sample` tableau introduced in the `toString` specification, `leastSet()` should return the hand `[1ebc, 1fbc, 1hbc]`.

³The notation $\lceil x \rceil$, pronounced “ceiling of x ”, denotes the smallest integer $\geq x$. The notation $\lfloor x \rfloor$, pronounced “floor of x ”, denotes the largest integer $\leq x$. For example, $\lceil 6.001 \rceil = \lceil 6.821 \rceil = 7$, while $\lfloor 6.001 \rfloor = \lfloor 6.821 \rfloor = 6$.

Appendix B: SetDeck Contract

Public Constructor Methods:

public SetDeck ();

Creates a new deck with all 81 cards from the Game of Set.

public SetDeck (String [] cardStrings);

Assumes that `cardStrings` is a array of string representations of cards that has all 81 cards from the Game of Set exactly once. Returns a deck that will deal the cards in the order specified by the `cardStrings` array. I.e., the first call to `deal()` returns the card specified by `cardStrings[0]`, the second call to `deal()` returns the card specified by `cardStrings[1]`, etc. Throws a `RuntimeException` if `cardStrings` does not contain the string representations of all 81 cards exactly once.

This constructor is useful for testing purposes, since it allows complete control over the order in which cards are dealt from the deck. Otherwise, the cards are dealt in random order.

Public Instance Methods:

public SetCard deal ();

Returns a randomly chosen card from the deck after removing it from the deck.

public int size ();

Returns the number of cards left to deal in this deck.

public boolean isEmpty ();

Returns `true` if there are no cards left to deal in this deck. Otherwise returns `false`.

public String toString ();

Returns a string representation of this deck in the form `<SetDeck:size=n>`, where *n* is the number of cards left in the deck.

Appendix C: SetGame Contract

A `SetGame` instance represents a game of CS230 Set. Conceptually, a the state of a game consists of a deck and a tableau with a specified number of cards. The game can be played for any size of tableau between 0 and 81.

```
public SetGame (int n);
```

Creates a new game with a tableau of `n` cards dealt from a new `SetDeck`.

```
public SetGame (int n, SetDeck d);
```

Creates a new game using a tableau of `n` cards dealt from the give deck `d`.

Public Instance Methods:

```
public SetHand [] interactive ();
```

Plays an interactive version of CS230 Set with the user via a crude text-based interface. Returns the array of sets won during the game (in the order they were won, not in hand order).

```
public SetHand [] automatic (boolean verbose);
```

Plays an automatic version of CS230 Set with a computer player that always chooses the least set from the available tableau (if there is one). Returns the array of sets won during the game (in the order they were won, not in hand order). The `verbose` flag controls the display of information during the game. If `verbose` is `true`, the tableaux and automatic player choices are displayed at each point of the game. If `verbose` is `false`, no text is displayed during the game.

Public Class Methods:

```
public static void main (String [] args);
```

The `SetGame` main method can be invoked as follows from a Linux shell:

- `java SetGame interactive n` invokes `new SetGame(n).interactive()`.
- `java SetGame interactive` invokes `new SetGame(12).interactive()`.
- `java SetGame automatic n bool` invokes `new SetGame(n).automatic(bool)`.
- `java SetGame automatic n` invokes `new SetGame(n).automatic(true)`.
- `java SetGame automatic` invokes `new SetGame(12).automatic(true)`.

*Problem Set Header Page
Please make this the first page of your hardcopy submission.*

CS230 Problem Set 2

Due 6pm Tuesday February 17

Names of Team Members:

Date & Time Submitted:

Collaborators (*anyone you or your team collaborated with*):

By signing below, I/we attest that I/we have followed the collaboration policy as specified in the Course Information handout.

Signature(s):

*In the **Time** column, please estimate the time you or your team spent on the parts of this problem set. Team members should be working closely together, so it will be assumed that the time reported is the time for each team member. Please try to be as accurate as possible; this information will help me design future problem sets. I will fill out the **Score** column when grading your problem set.*

Part	Time	Score
General Reading		
Problem 1 [65]		
Problem 2 [15]		
Problem 3 [20]		
Total		