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Homework 1: Packages, Interfaces, Generics, Exceptions, Iteration

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Getting the Skeleton Files

Just the usual `git pull skeleton master`.

Introduction

In this homework, you will learn how to write and use packages, as well as get some hands-on practice with interfaces and abstract classes. We'll also get an opportunity to implement a simple data structure as well as an algorithm that is easy to implement given that data structure. Finally we'll add support for iteration and exceptions (which we'll cover on Monday) to our data structure.

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organizes a set of related classes and interfaces. Conceptually you can think of packages as being similar to different folders on your computer. When you are building a large system, it is a good idea to organize it into different packages.

For this assignment, we'll create a synthesizer package intended for use by programs that want to simulate the sound of instruments.

The synthesizer package has four components:

- `BoundedQueue`, an interface which declares all the methods that must be implemented by any class that implements `BoundedQueue`.
- `AbstractBoundedQueue`, an abstract class which implements `BoundedQueue`, capturing the redundancies between methods in `BoundedQueue`.
- `ArrayRingBuffer`, a class which extends `AbstractBoundedQueue` and uses an array as the actual implementation of the `BoundedQueue`.
- `GuitarString`, which uses an `ArrayRingBuffer<Double>` to implement the Karplus-Strong algorithm to synthesize a guitar string sound.

We've provided you with skeleton code for `ArrayRingBuffer` and `GuitarString`, but you'll need to implement the other two .java files from scratch. In this HW, we'll work our way down the hierarchy from most abstract to most concrete.

Note: While it'd probably be better design to make only the GuitarString class public (since people using synthesizers don't really care about AbstractBoundedQueues), we'll be leaving all of our classes public for this HW for testing convenience.

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Task 1: BoundedQueue

Review: What is an Interface? Why would you want one?

As discussed in class, an interface is a formal contract between a class and the outside world. If your class claims to implement an interface, then all methods defined by that interface must appear in your class (or somewhere in your superclass) before the class will successfully compile. This is a way of enforcing promised behavior. All methods that you declare or define are automatically public and abstract (even if you omit the `public` keyword).

Your Task

We will start by defining a BoundedQueue interface. The BoundedQueue is similar to our Deque from project 1, but with a more limited API. Specifically, items can only be enqueued at the back of the queue, and can only be dequeued from the front of the queue. Unlike our Deque, the BoundedDeque has a fixed capacity, and nothing is allowed to enqueue if the Deque is full.

Create a file `BoundedQueue.java` in the synthesizer folder. Your BoundedQueue interface should contain the following public abstract methods:

```
int capacity();          // return size of the buff
int fillCount();         // return number of items
void enqueue(T x);  // add item x to the end
T dequeue();        // delete and return item from
T peek();           // return (but do not delete) i
```

You should also create default methods `isEmpty()` and `isFull()` that return the appropriate answer if the BoundedQueue is empty or full.

```
default boolean isEmpty()       // is the buffer em
default boolean isFull()        // is the buffer fu
```

capacity 4, the state of the queue after each operation is shown below:

```
isEmpty()       //                          (returns t
enqueue(9.3)    // 9.3
enqueue(15.1)   // 9.3  15.1
enqueue(31.2)   // 9.3  15.1  31.2
isFull()        // 9.3  15.1  31.2          (returns f
enqueue(-3.1)   // 9.3  15.1  31.2  -3.1
isFull()        // 9.3  15.1  31.2  -3.1 (returns t
dequeue()       // 15.1 31.2  -3.1          (returns 9
peek()          // 15.1 31.2  -3.1          (returns 1
```

Of course, your `BoundedQueue.java` file won't actually do anything (since it's an interface), but it will define the contract that any `BoundedQueue` must follow.

Make sure to decare this interface as part of the `synthesizer` package. The syntax for declaring yourself to be part of a package is `package <packagename>;` . For example, if you are part of the `animal` package, the top of your file should have a `package animal;` line. Your package name should just be `synthesizer` , nothing else.

Before moving on, ensure that `BoundedQueue` compiles: `javac BoundedQueue.java` .

If you're stuck, see the List61B interface for an example of an interface declaration with generics.

Task 2: AbstractBoundedQueue

Review: What is an Abstract Class? Why would you want one?

Methods and classes can be declared as abstract using the abstract keyword. Abstract classes cannot be instantiated, but they can be subclassed using the `extends` keyword. Unlike interfaces, abstract classes can provide

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methods, including instance variables.

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Classes that implement interfaces will inherit all of the methods and variables from that interface. If an implementing class fails to implement any abstract methods inherited from an interface, then that class must be declared abstract, as in:

```
public abstract class AbstractBoundedQueue
```

As an aside, it is also possible to declare additional abstract methods. To do so, the method must be defined with the abstract keyword and without an implementation (without braces, and followed by a semicolon), like this:

```
abstract void moveTo(double deltaX, double deltaY);
```

We won't explicitly define any non-inherited methods as abstract in HW1, but it's a thing you might find useful someday (perhaps in the HugLife lab during week 6).

Your Task

Create a new abstract class in a .java file called `AbstractBoundedQueue.java` that implements `BoundedQueue`. Your `AbstractBoundedQueue` class should have the following methods and fields (field is just another word for variable):

```
protected int fillCount;
protected int capacity;
public int capacity()
public int fillCount()
public boolean isEmpty()
public boolean isFull()
public abstract T peek();
public abstract T dequeue();
public abstract void enqueue(T x);
```

Note that `isEmpty`, `isFull`, `peek`, `dequeue`, `enqueue`, are inherited from BoundedQueue, so *you should not to declare these explicitly in your AbstractBoundedQueue.java* file. The mysterious `protected` keyword above is something subclasses of AbstractBoundedQueue can access this variable.

The purpose of `AbstractBoundedQueue` will be to simply provide a protected `fillCount` and `capacity` variable that all subclasses will inherit, as well as so called "getter" methods `capacity()` and `fillCount()` that return `capacity` and `fillCount`, respectively. This saves a tiny amount of work for future implementations like `ArrayRingBuffer.java` (see next section).

If you're having trouble compiling your `AbstractBoundedQueue.java` file from the command line, because the compiler can't find `BoundedQueue.class`, try compiling with:

```
javac BoundedQueue.java AbstractBoundedQueue.java
```

or if you want to compile ALL java files in a folder, you can just do:

```
javac *.java
```

This is a minor quirk in the way the javac compiler behaves when compiling from inside package directories.

Side note: When to Use a Interface versus Abstract Class

In practice, in can be a little unclear when to use an interface and when to use an abstract class. One mostly accurate metaphor that might help is that you can think of an interface as defining a "can-do" or an "is-a" relationship, whereas an abstract class should be a stricter "is-a" relationship. The difference can be subtle, and you can often use one instead of the other.

In practice, large Java libraries often have a hierarchy of interfaces, which are extended by abstract classes that provided default implementations for some methods, and which are in turn ultimately implemented by concrete classes.

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(which is its superinterface), and is implemented by many subinterfaces (i.e. List, Set, Map), which in turn have their own abstract implementations (AbstractList, AbstractSet AbstractMap). However, for smaller programs, the hierarchy is often stubbier, sometimes starting with an abstract class. For example, we could have just started with `AbstractBoundedQueue` at the top of the hierarchy and skipped having a `BoundedQueue` interface altogether.

Task 3: ArrayRingBuffer

The `ArrayRingBuffer` class will do all the real work by extending `AbstractBoundedQueue`. That means we can happily inherit `capacity()`, `fillCount()`, `isEmpty()`, and `isFull()` without having to override these, but we'll need to override all of the the abstract methods. In this part, you'll fill out `ArrayRingBuffer.java`. You'll need to rename the file from `ArrayRingBuffer.java.skeleton` to `ArrayRingBuffer.java`.

A naive array implementation of a BoundedQueue would store the newest item at position 0, the second newest item in position 1, and so forth. This is an inefficient approach, as we see in the example below, where the comments show entries 0, 1, 2, and 3 of the array respectively. We assume that the array is initially all nulls.

```
BoundedQueue x = new NaiveArrayBoundedQueue(4);
x.enqueue(33.1) // 33.1 null null  null
x.enqueue(44.8) // 33.1 44.8 null  null
x.enqueue(62.3) // 33.1 44.8 62.3  null
x.enqueue(-3.4) // 33.1 44.8 62.3 -3.4
x.dequeue()     // 44.8 62.3 -3.4  null (returns 33
```

Note that in this setup, the call to `dequeue` is very slow as it requires moving every single item to the left. For larger arrays this would result in unacceptable performance.

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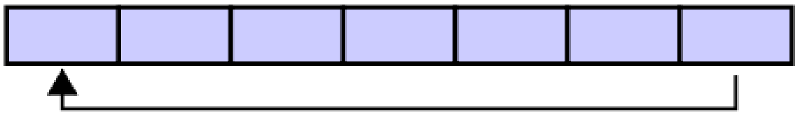
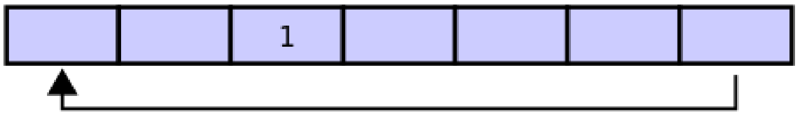
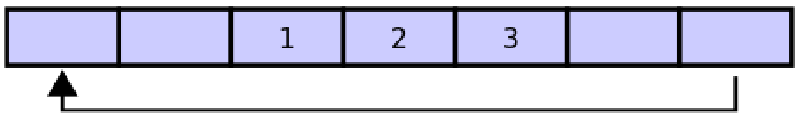
using the "ring buffer" data structure, similar to the circular array from project 1a. A ring buffer first starts empty and of some predefined length. For example, this is a 7-element buffer:



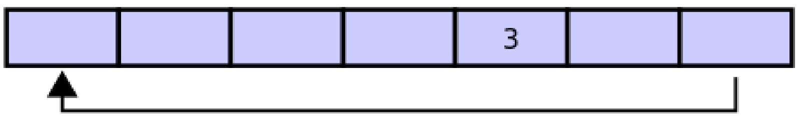
Assume that a 1 is written into the middle of the buffer (exact starting location does not matter in a ring buffer):



Then assume that two more elements are added — 2 & 3 — which get appended after the 1. Here, it is important that the 2 and 3 are placed in the exact order and places shown:



If two elements are then removed from the buffer, the oldest two values inside the buffer are removed. The two elements removed, in this case, are 1 & 2, leaving the buffer with just a 3:



If we then enqueue 4, 5, 6, 7, 8, 9, the ring buffer is now as shown below:

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Note that the 6 was enqueued at the leftmost entry of the array (i.e. the buffer wraps around, like a ring). At this point, the ring buffer is full, and if another enqueue() is performed, then an Exception will occur. You will manually throw this Exception. See the section labeled Iteration and Exceptions at the end of this HW for more.

We recommend you maintain one integer instance variable `first` that stores the index of the least recently inserted item; maintain a second integer instance variable `last` that stores the index one beyond the most recently inserted item. To insert an item, put it at index `last` and increment `last` . To remove an item, take it from index `first` and increment `first` . When either index equals capacity, make it wrap-around by changing the index to 0. Our skeleton file provides starter code along these lines. You're welcome to do something else if you'd like, since these variables are private and thus our tester will not be able to see them anyway.

In the last section of this homework, we'll implement our `ArrayRingBuffer` to throw a run-time exception if the client attempts to `enqueue()` into a full buffer or call `dequeue()` or `peek()` on an empty buffer. We'll be covering exceptions on Monday, so hold off until then (or read ahead in HFJ or online).

Once you've fleshed out the TODOs, make sure `ArrayRingBuffer` compiles before moving on. Optionally, you can add tests to the `TestArrayRingBuffer` class (either before or after your write `ArrayRingBuffer`). `TestArrayRingBuffer.java` will not be graded. To run TestArrayRingBuffer you'll need to run the following command from your hw1 folder as described in this common package gotchas slide.

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For homeworks and labs (but not projects), you're welcome to share test code. Feel free to share your tests for this HW on Piazza.

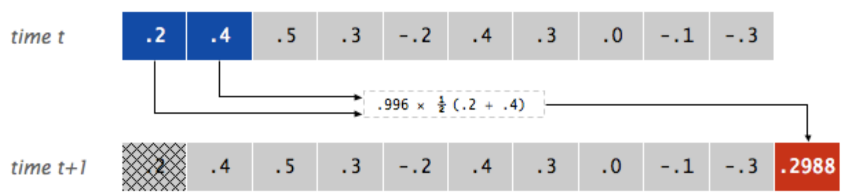
Task 4: GuitarString

Finally, we want to flesh out `GuitarString` , which uses an `ArrayRingBuffer` to replicate the sound of a plucked string. We'll be using the Karplus-Strong algorithm, which is quite easy to implement with a BoundedQueue.

The Karplus-Algorithm is simply the following three steps:

1. Replace every item in a BoundedQueue with random noise (double values between -0.5 and 0.5).
2. Remove the front double in the BoundedQueue and average it with the next double in the BQ (hint: use `dequeue()` and `peek()`) multiplied by an energy decay factor of 0.996.
3. Play the double that you dequeued in step 2. Go back to step 2 (repeating forever).

Or visually, if the BoundedQueue is as shown on the top, we'd dequeue the 0.2, combine it with the 0.4 to form 0.2988, enqueue the 0.2988, and play the 0.2.



the Karplus-Strong update

You can play a double value with the StdAudio.play() method. For example StdAudio.play(0.333) will tell the diaphragm of your speaker to extend itself to 1/3rd of its total reach, StdAudio.play(-0.9) will tell it to stretch its little heart backwards almost as far as it can reach. Movement of the

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nice patterns, these disruptions will be intepreted by your consciousness as pleasing thanks to billions of years of evolution. See this page for more. If you simply do StdAudio.play(0.9) and never play anything again, the diaphragm shown in the image would just be sitting still 9/10ths of the way forwards.

Rename `GuitarString.java.skeleton` to `GuitarString.java`. Complete 'GuitarString.java' so that it implements steps 1 and 2 of the Karplus-Strong algorithm. Step 3 will be done by the client of the `GuitarString` class.

For example, the provided `TestGuitarString` class provides a sample test `testPluckTheAString` that attempts to play an A-note on a guitar string. You should hear an A-note when you run this test. If you don't, you should try the `testTic` method and debug from there. Consider adding a `print` or `toString` method to `GuitarString.java` that will help you see what's going on between tics.

Once you're relatively comfortable that GuitarString should be working, try compiling and running 'GuitarHeroLite'. It will provide an interface, allowing the user to interactively play sounds using the `synthesizer` package's `GuitarString` class.

When you run `GuitarHeroLite`, it will open a Standard Draw window. Click on the window, and press "a" or "c". These should play two different guitar string sounds for you. This is just the sound of a double dequeuing repeatedly. It is like magic.

Just For Fun: Building a 37 Key Synthesizer

Write a program GuitarHero that is similar to GuitarHeroLite, but supports a total of 37 notes on the chromatic scale from keyboard, from lowest note to highest note:

```
String keyboard = "q2we4r5ty7u8i9op-[=zxdcfvgbnjmk,
```

This keyboard arrangement imitates a piano keyboard: The "white keys" are on the qwerty and zxcv rows and the "black keys" on the 12345 and asdf rows of the keyboard.

The ith character of the string keyboard corresponds to a frequency of 440 × 2^((i - 24) / 12), so that the character 'q' is 110Hz, 'i' is 220Hz, 'v' is 440Hz, and ' ' is 880Hz. Don't even think of including 37 individual GuitarString variables or a 37-way if statement! Instead, create an array of 37 GuitarString objects and use keyboard.indexOf(key) to figure out which key was typed. Make sure your program does not crash if a key is pressed that does not correspond to one of your 37 notes.

This part of the assignment is not graded.

Even More Fun

- Harp strings: Flipping the sign of the new value before enqueueing it in tic() will change the sound from guitar-like to harp-like. You may want to play with the decay factors to improve the realism, and adjust the buffer sizes by a factor of two since the natural resonance frequency is cut in half by the tic() change.
- Drums: Flipping the sign of a new value with probability 0.5 before enqueueing it in tic() will produce a drum sound. A decay factor of 1.0 (no decay) will yield a better sound, and you will need to adjust the set of frequencies used.
- Guitars play each note on one of 6 physical strings. To simulate this you can divide your GuitarString instances

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other strings in that group.

- Pianos come with a damper pedal which can be used to make the strings stationary. You can implement this by, on iterations where a certain key (such as Shift) is held down, changing the decay factor.
- While we have used equal temperament, the ear finds it more pleasing when musical intervals follow the small fractions in the just intonation system. For example, when a musician uses a brass instrument to play a perfect fifth harmonically, the ratio of frequencies is 3/2 = 1.5 rather than 27/12 ~ 1.498. Write a program where each successive pair of notes has just intonation.

This part of the assignment is not graded.

Why It Works

The two primary components that make the Karplus-Strong algorithm work are the ring buffer feedback mechanism and the averaging operation.

- The ring buffer feedback mechanism. The ring buffer models the medium (a string tied down at both ends) in which the energy travels back and forth. The length of the ring buffer determines the fundamental frequency of the resulting sound. Sonically, the feedback mechanism reinforces only the fundamental frequency and its harmonics (frequencies at integer multiples of the fundamental). The energy decay factor (.996 in this case) models the slight dissipation in energy as the wave makes a round trip through the string.
- The averaging operation. The averaging operation serves as a gentle low-pass filter (which removes higher frequencies while allowing lower frequencies to pass, hence the name). Because it is in the path of the

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higher harmonics while keeping the lower ones, which corresponds closely with how a plucked guitar string sounds.

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Task 5: Iteration and Exceptions

As an exercise in making your data structures more industrial strength, we'll add the ability to iterate through a BoundedQueue and also ensure that it throws exceptions when given invalid inputs. We'll cover these topics on Monday 2/22.

BoundedQueue

First, modify your `BoundedQueue<T>` interface so that it `extends Iterable<T>` and add the required abstract method to the interface. You'll need to `import java.util.Iterator`.

AbstractBoundedQueue

Consider your AbstractBoundedQueue. You don't need to change anything in this class to support iteration. Make sure you understand why.

ArrayRingBuffer

Now finally add the required `iterator()` method to `ArrayRingBuffer`. You'll need to define a private class that implements the `Iterator` interface. See lecture 14 for an example: github slides.

Exceptions

Now modify `ArrayRingBuffer` so that it throws a `RuntimeException` with the String "Ring Buffer Overflow" when a user attempts to enqueue into a full attempts to deque an empty `ArrayRingBuffer`.

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Submission

To submit this assignment, you must upload a .zip file containing your synthesizer folder. More detailed instructions coming later if you run into issues.

Frequently Asked Questions

My AbstractBoundedQueue won't compile because BoundedQueue isn't found.

Look more closely at the AbstractBoundedQueue section of this assignment page for tips.

I'm getting a "class file contains wrong class" error.

Make sure all of your Java files have the right package declaration at the top. Also make sure that anything that is part of the synthesizer package is in the synthesizer folder.

I'm getting a message that I did not override an abstract method, but I am!

Chances are you have a typo. You should always use the @Override tag when overriding methods so that the compiler will find any such typos.

I'm getting ... in AbstractBoundedQueue and ... in BoundedQueue have the same erasure, yet neither overrides the other.

Make sure your classes are defined as

`AbstractBoundedQueue<T> implements BoundedQueue<T>`

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When I try to run the provided tests I get "No runnable methods".

Make sure you've uncommented the tests, including the `@Test` annotation.

I'm failing the nested iteration test. What does this mean?

Consider what happens when you run the following:

```
int[] someInts = new int[]{1, 2, 3};
for (int x : someInts) {
    for (int y: someInts) {
        System.out.println("x: " + x +  ", y:" + y)
    }
}
```

And think about how your code is not doing what is listed above.

When I try to compile my code, it says type K#1 is not compatible with type K#2, or something similar.

If you're defining an inner class, make sure it does not redeclare a new generic type parameter, e.g. the first `<Z>` given in `private class MapWizard<Z> implements Iterator<Z>{` should not be there!

I'm getting a "No JSON object could be decoded" error.

While `GuitarString` is a guitar string simulator, it should not involve playing any sounds. The playing should be done by the `GuitarString` client.

Do I need to implement `remove()` from the Iterator interface?

Classically, when you implement an interface, you need to write the actual definition of every declared method. However, in Java 8, `remove()` is a default method.

Credits: RingBuffer figures from wikipedia. This assignment adapted from Kevin Wayne's Guitar Heroine assignment.

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