Iteration & Inner Classes

Lecture 16
CS211 – Summer 2007

Announcements

- Assignment #4 posted on website
- Weren't in class yesterday?
  - Graded prelims are available from the consulting office
  - Regrade request forms also in consulting office
  - Deadline for prelim regrade requests: next Wednesday 7/24

Recall: Linear Search

```
boolean linearSearch(Integer[] a, Object v) {
   for (int i = 0; i < a.length; i++) {
      if (a[i].compareTo(v) == 0) return true;
   }
   return false;
}
```

- Will this work?

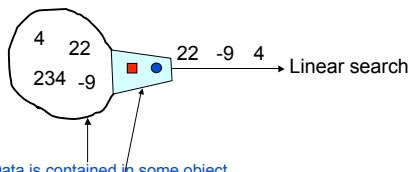
```
boolean linearSearch(Object[] a, Object v) {
   for (int i = 0; i < a.length; i++) {
      if (a[i].compareTo(v) == 0) return true;
   }
   return false;
}
```


Recall: Linear Search

```
boolean linearSearch(Comparable[] a, Object v) {
   for (int i = 0; i < a.length; i++) {
      if (a[i].compareTo(v) == 0) return true;
   }
   return false;
}
```

- Relies on data being stored in a 1D array
  - Will not work if data is stored in another data structure such as a 2D array, list, stack, queue, ...
- All linear search *really needs* is:
  - Are there more elements to look at?
  - If so, get me the next element

Goal: Generic Linear Search



- Data is contained in some object
- Object has an adapter that permits data to be enumerated in some order
- Adapter has two methods
  - `boolean hasNext()`: are there more elements?
  - `Object next()`: if so, give me a new element that has not been enumerated so far

Linear Search

- First version:
  - Input was `int[]`, used `==` to compare elements
- More generic version:
  - Input was `Comparable[]`, used `compareTo()`
- Is there a still more generic version that is independent of the data structure?
  - For example, works even with `Comparable[][]`
- In other words, how should we iterate?
  - Goal: perform some action on *each item* in a collection

Strategy I: Copy to an Array

- Copy the entire collection into an array, then iterate over the array
- Pro:
  - Straightforward to implement
- Con:
  - Can involve a lot of copying
    - A *lazy* method might be better

Strategy I(b): Emulate an array

- Alternate version: Provide an array-like interface
  - `numItems()`
  - `getItem(int i)`
- Bad
  - It can be expensive to determine the i^{th} item
  - It doesn't always make sense to refer to the i^{th} item in a collection

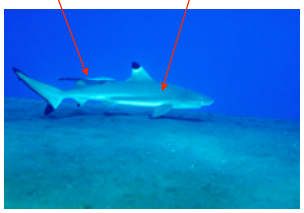
Strategy II: Iteration-State as Part of Collection

- The collection itself keeps track of iteration
  - Implies need for methods equivalent to
    - `void resetIteration()`
    - `boolean hasNext()`
    - `Object getNext()`
- Bad
  - Just one iteration active at a time
  - Makes it hard to share the collection

Sharks and Remoras

`Iterator` implementation is like a remora

Data class is like shark



A single shark must allow many remoras to hook to it

Strategy III: `Iterator` as a Separate Object

- Create an `Iterator` object
  - It maintains the state of the iteration
- Java provides an interface (`java.util.Iterator`) for this purpose

Remora teeth

- Good
  - Can have multiple iterator objects associated with one collection
  - Standard interface for all iterations
- Bad
  - The iterator object has to know a lot about the internal structure of the collection
    - We'll see how to use inner classes to fix this

`Iterator` Interface

- `java.util.Iterator`
  - Linear search can be written once and for all using Iterator interface
- Any data structure that wants to support iteration should provide an implementation of `Iterator`
  - We look at three ways to implement `Iterator`
    - Using a separate class
    - Using an inner class
    - Using an anonymous inner class

```
interface Iterator {
   public boolean hasNext();
   public Object next();
   //Optional
   public void remove();
}
```

`Enumeration` Interface

```
interface Enumeration {
   boolean hasMoreElements();
   Object nextElement();
}
```

- You may see some code that uses the `Enumeration` interface instead of the `Iterator` interface
  - `Enumeration` was part of the earliest versions of Java
  - Similar functionality to `Iterator` (no `remove` method)
  - `Iterator` is preferred

`Iterable` Interface

- Java also provides a standard interface (`java.lang.Iterable`) for anything that can be iterated

```
interface Iterable {
   public Iterator iterator();
}
```

- An object that implements `Iterable` can be used in an enhanced `for`-loop (later in lecture)

Generic Linear Search

Array version

```
boolean linearSearch (Object[] a, Object v) {
   for (int i = 0; i < a.length; i++) {
      if (a[i].equals(v)) return true;
   }
   return false;
}
```

`Iterator` version

```
boolean linearSearch (Iterator it, Object v) {
   while (it.hasNext()) {
      if (it.next().equals(v)) return true;
   }
   return false;
}
```


How Do We Create an `Iterator`?

- `Iterator` is a Java *interface*, so we must create a class that *implements* `Iterator`
- To create an `Iterator` for class `X`, we can
  - Use a separate class
  - Use an inner class within `X`
  - Use an anonymous inner class within `X`

An Array Iterator (Version 1)

```
class ArrayIterator implements Iterator {
   private Object[] data;
   private int index = 0; //index of next element

   public ArrayIterator (Object[] a) {
      data = a;
   }
   public boolean hasNext() {
      return (index < data.length);
   }
   public Object next() {
      if (this.hasNext()) return data[index++];
      else throw new NoSuchElementException();
   }
   public void remove() {
      throw new UnsupportedOperationException();
   }
}
```


Using the Array Iterator

```
String[] a = {"Hello", "world"};

//Printing
Iterator iter = new ArrayIterator(a);
while (iter.hasNext()) {
   System.out.println(iter.next());
}

//Searching
iter = new ArrayIterator(a);
if (linearSearch(iter,"world")) {
   System.out.println("found!");
}
```

`Iterator` Features

- Can create as many iterators as needed
  - Multiple iterators over same data set are fine (as long as the data set isn't changed during iteration)
- Works for most data structures
  - Example: 2D arrays
    - Can keep two cursors, one for row, one for column
    - Standard orders of enumeration
      - Row-major
      - Column-major

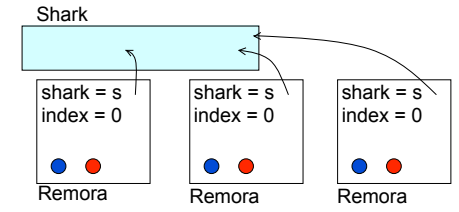

```
class Array2DIterator implements Iterator {
   private Object[][] data;
   private int rowIndex = 0, colIndex = 0;

   public Array2DIterator(Object[][] a) { data = a; }

   public boolean hasNext() {
      while (rowIndex < data.length &&
             colIndex >= data[rowIndex].length) {
         rowIndex++; colIndex = 0; //if end of row
      }
      return (rowIndex < data.length &&
              colIndex < data[rowIndex].length);
   }
   public Object next() {
      if (hasNext()) return data[rowIndex][colIndex++];
      else throw new NoSuchElementException();
   }
   public void remove() {
      throw new UnsupportedOperationException();
   }
}
```


Code for Sharks and Remoras

```
class Shark implements Iterable {
   public Object[] data;
   public Shark (Object[] a) { data = a; }
   public Iterator iterator() { return new Remora(this); }
}
class Remora implements Iterator {
   private int index = 0;
   private Shark shark;
   public Remora(Shark s) { shark = s; }
   public boolean hasNext() {
      return (index < shark.data.length);
   }
   public Object next() {
      if (hasNext()) return shark.data[index++];
      else throw new NoSuchElementException();
   }
   public void remove () {
      throw new UnsupportedOperationException();
   }
}
```

Client Code

```
String[] a = {"Hello", "world"};
Shark s = new Shark(a); //object containing data
boolean b = linearSearch(s.iterator(), "Hello");
boolean c = linearSearch(s.iterator(), "world");
boolean d = linearSearch(s.iterator(), "Bye");
```



Critique: `Iterator` as Separate Class

- Good
  - `Shark` class focuses on data
  - `Remora` class focuses on iteration
- Bad
  - `Remora` code relies on being able to access `Shark` variables such as data array
    - What if data were declared private?
  - `Remora` is specialized to `Shark`, but code appears outside `Shark` class
    - We may change `Shark` class and forget to update `Remora`
  - Clients can create `Remora`s without invoking `iterator()` method of `Shark`
    - Better to have language construct to enforce convention

Better: `Iterator` as an Inner Class

- Java allows you declare a class within another class
  - Inner class
- Inner classes can occur at many levels within a class
  - Member level
    - Inner class defined as if it were another field or method
  - Statement level
    - Inner class defined as if it were a statement in a method
  - Expression level
    - Inner class defined as it were part of an expression
    - Such expression-level classes are called anonymous classes
- Initially, we focus on member-level inner classes

Example of an Inner Class

```
class Shark implements Iterable {
  private Object[] data;
  public Shark(Object[] a) { data = a; }
  public Iterator iterator() {return new Remora();}
  private class Remora implements Iterator {
    private int index = 0;
    public boolean hasNext() {
      return (index < data.length);
    }
    public Object next() {
        if (hasNext()) return data[index++];
        else throw new NoSuchElementException();
    }
    public void remove() {
      throw new UnsupportedOperationException();
    }
  }
}
```

Client Code

```
String[] a = {"Hello", "world"};
Shark s = new Shark(a);
boolean b = linearSearch(s.iterator(), "Hello");
```


Observations

- Inner class can be declared **`public`**, **`private`**, "package", or **`protected`**
  - Inner class name is visible accordingly
- Instances of an inner class have access to *all* members of containing outer-class instance
  - *Even members declared* **`private`**
- Some inner-class syntax is weird
  - Inner classes that are public can be instantiated by **`outerObjectInstance.new InnerClass()`**
    - E.g., `Shark.new Remora()`
  - Note that **`new Shark.Remora()`** does not work
  - If you find yourself needing this syntax, you are probably using a bad design

Inner Classes & `this`

- Keyword **`this`** in **`Remora`** class refers to **`Remora`** object-instance, not outer **`Shark`** object-instance
- How do we get a reference to **`Shark`** from **`Remora`**?
  - Here's one way:

```
class Shark {
  private Shark kahuna;
  public Shark() { kahuna = this; }

  class Remora{ //inner class
    ...kahuna... //inner class can access variable
  }
}
```

  - Here's another way: **`Shark.this`** refers to the outer **`Shark`** object-instance

Anonymous Classes

- To permit programmers to write inner classes compactly, Java permits programmers to write anonymous classes
  - Class does not have a name
  - Must be instantiated at the point where it is defined

Anonymous Class Example

```
class Shark implements Iterable {
   public Object[] data;
   public Shark(Object[] a) { data = a; }
   public Iterator iterator() {return new ~~Remora();~~

   ~~class Remora implements~~ Iterator() {
      private int index = 0;
      public boolean hasNext() {
         return (index < data.length);
      }
      public Object next() {
         if (hasNext()) return data[index++];
         else throw new NoSuchElementException();
      }
      public void remove() {
         throw new UnsupportedOperationException();
      }
   }
}
```


Anonymous Class Example

```
class Shark implements Iterable {
   private Object[] data;
   public Shark (Object[] a) { data = a; }
   public Iterator iterator () {
      return new Iterator () {
         private int index = 0;
         public boolean hasNext() {
            return (index < data.length);
         }
         public Object next() {
            if (hasNext()) return data[index++];
            else throw new NoSuchElementException();
         }
         public void remove () {
            throw new UnsupportedOperationException();
         }
      };
   }
}
```

Anonymous Class Properties

- An anonymous class is an inner class with the usual class body, but
  - No class name
  - No access specifier (i.e., no `public`/`private`/`protected`)
  - No constructor
  - No explicit `extends` or `implements`
    - It either extends one class or implements one interface

```
new classOrInterfaceName() { ...body... }
```


Anonymous Class Examples

- To specify an anonymous class (call it `A`) that extends class `P`
  - `new P() { ... };  //create instance of A`
  - `new P(42) { ... }; //calls different P-constructor`
  - `P x = new P() { ... }; //assignment`
- To specify an anonymous class (call it `A`) that implements interface `I`
  - `new I() { ... };  //create instance of A`
  - `I y = new I() { ... }; //assignment`
- Anonymous class can override methods of superclass `P` or implement interface methods of `I`
- All other methods and fields are effectively `private`
  - Because there is no way to invoke them from outside!

Enhanced `for`-loop (`foreach`)

- As of Java 5, a `for`-loop works with
  - Any array type
  - Anything that implements the `Iterable` interface

`Iterator` version

```
boolean linearSearch(Iterator a, Object v) {
   while (a.hasNext())
      { if (a.next().equals(v)) return true; }
   return false;
}
```

`Iterable` version

```
boolean linearSearch(Iterable b, Object v) {
   for (Object x : b)
      { if (x.equals(v)) return true; }
   return false;
}
```


Conclusions

- `Iterator` interface allows one to write generic code
  - Works on data collections without regard to type of elements or data structure
- Inner classes are the best way to write an `Iterator`
- The `foreach` construct (i.e., enhanced `for`-loop) makes for more compact code, but
  - Cannot use if need access to array indices, for instance
  - Cannot use if need to use remove-operation of `Iterator`