

Announcements

- Office Hours today: 3-4
- Prelims Graded:
 - Grades and solution on CMS by 1pm
 - Set up meeting if don't understand grading or think there is a mistake.
- Mid-session Feedback: how are we doing?
 - Should get survey by email later today.
 - Help us improve
 - Counts as a quiz grade

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Iteration & Inner Classes

Lecture 16
CS2110 – Summer 2008

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;  
}
```

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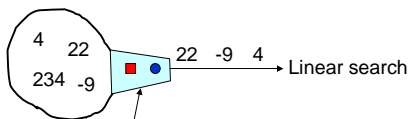
Recall: Linear Search

```
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

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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

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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

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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

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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

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Strategy II: Iteration-State as Part of Collection

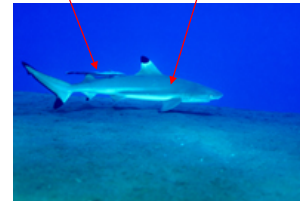
- The collection itself keeps track of iteration
 - Implies need for methods equivalent to
 - `void resetIteration()`
 - `boolean hasNext()`
 - `Object getNext()`
- Bad
 - Just one iteration active at a time
 - Makes it hard to share the collection

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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

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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
- 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



Remora teeth

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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();
}
```

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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

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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)

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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;
}
```

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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`

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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();
    }
}
```

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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!");
}
```

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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

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```
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();
    }
}
```

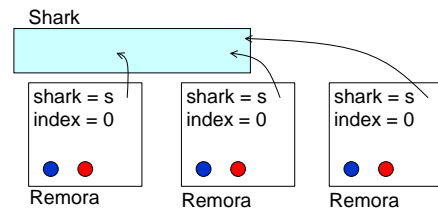
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Code for Sharks and Remoras

```
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");
```



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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 Remoras without invoking iterator() method of Shark
 - ♦ Better to have language construct to enforce convention

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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 if it were part of an expression
 - ♦ Such expression-level classes are called anonymous classes
- Initially, we focus on member-level inner classes

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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");
```

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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

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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

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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

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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();
    }
}
```

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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();
            }
        };
    }
}
```

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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... }
```

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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!

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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;  
}
```

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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`

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