

Principles of Software Construction: Objects, Design, and Concurrency

Design Case Study: Java Collections

Fall 2014

Charlie Garrod Jonathan Aldrich

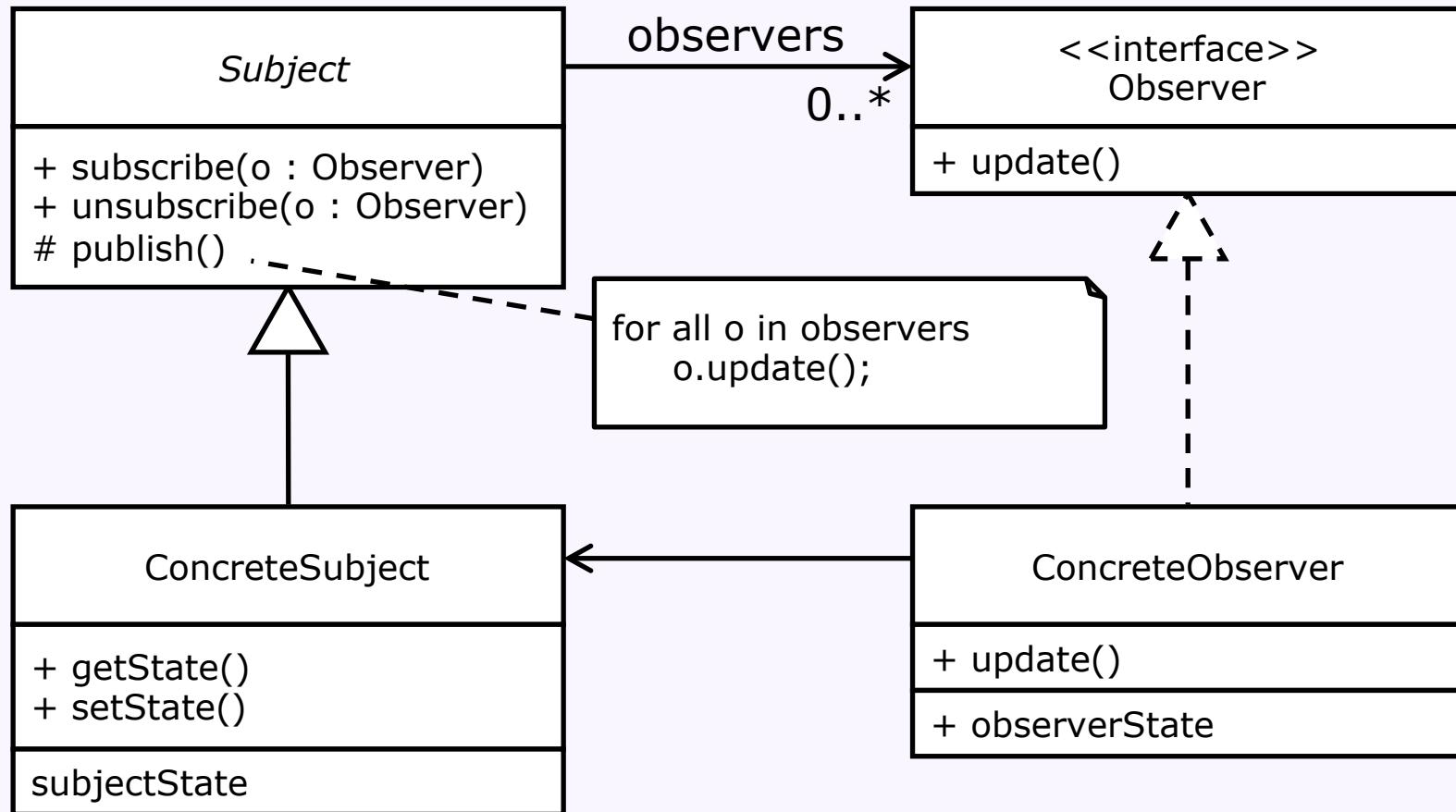
Administrivia

- No homework due next week
 - Start Homework 4b implementation soon...
- Graded midterm exams still available after class

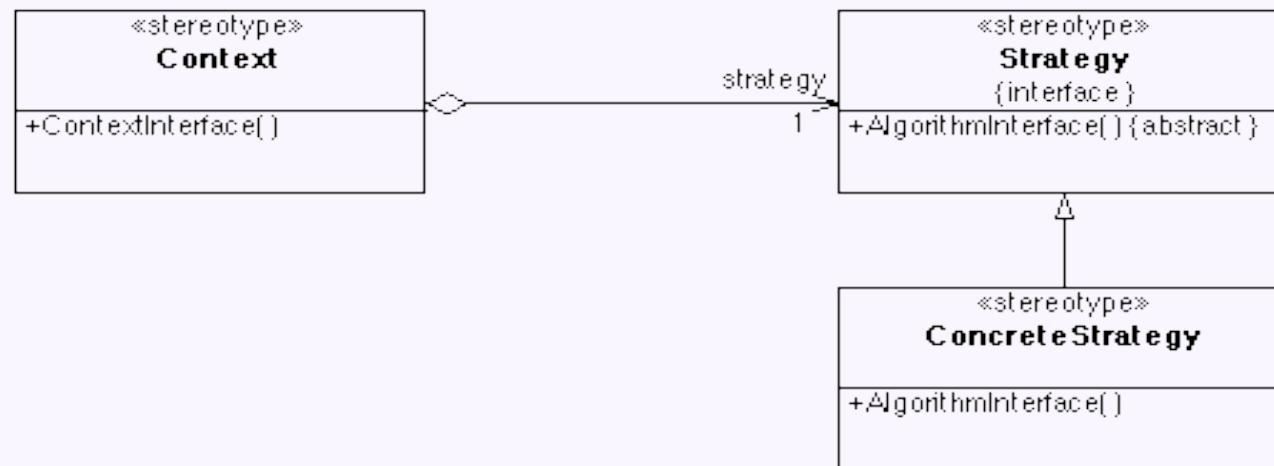
Key concepts from Tuesday

The Observer design pattern

- A.k.a. listener, a.k.a. publish/subscribe



The Strategy design pattern



Design patterns we have seen so far

Composite

Template Method

Adapter

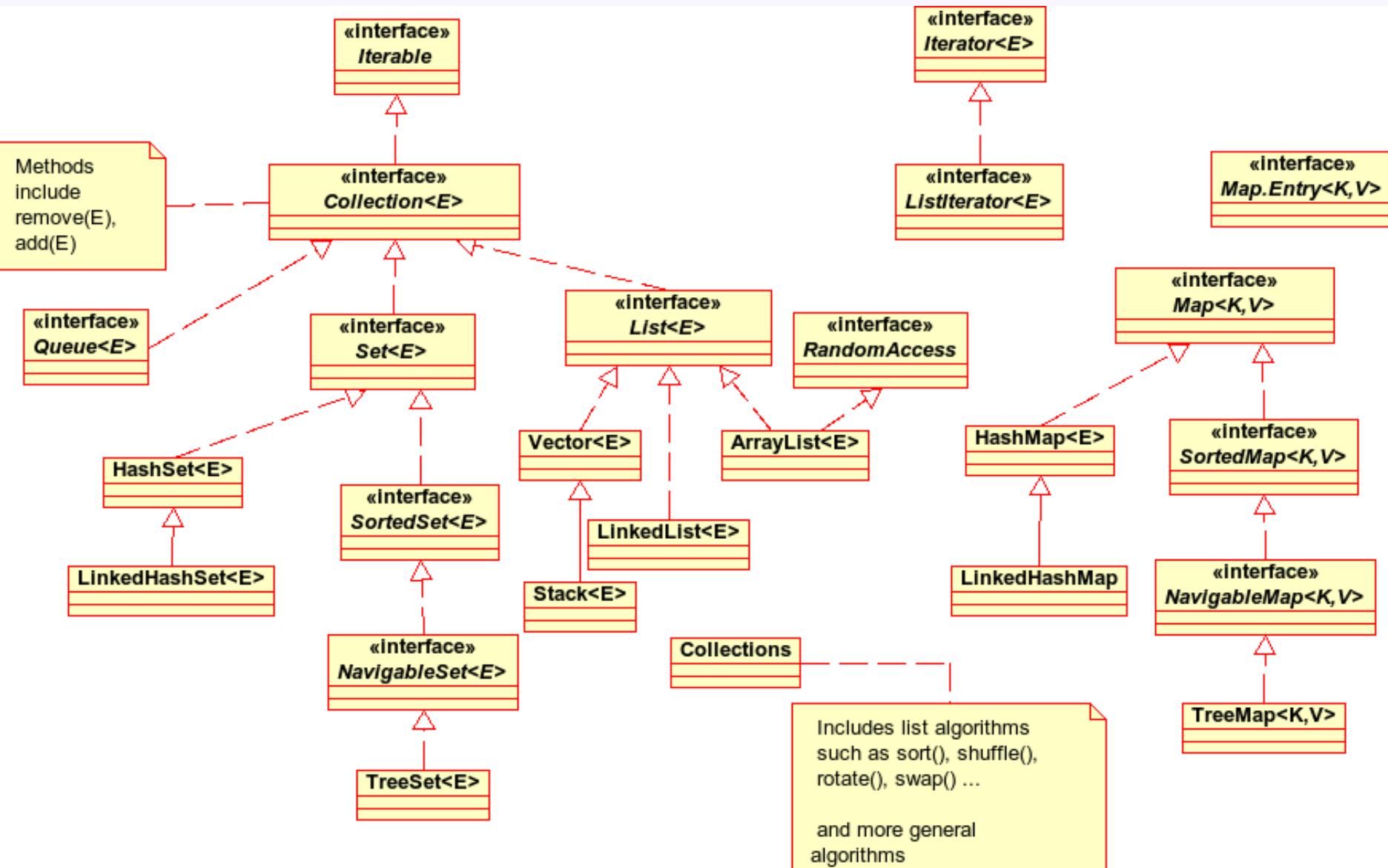
Strategy

Observer

Decorator

Model-View-Controller

Today: Java Collections



Learning goals for today

- Understand the design aspects of collection libraries.
- Recognize the design patterns used and how those design patterns achieve design goals.
 - Marker Interface
 - Decorator
 - Factory Method
 - Iterator
 - Strategy
 - Template Method
 - Adapter
- Be able to use common collection classes, including helpers in the Collections class.

Designing a data structure library

- Different data types: lists, sets, maps, stacks, queues, ...
- Different representations
 - Array-based lists vs. linked lists
 - Hash-based sets vs. tree-based sets
 - ...
- Many alternative designs
 - Mutable vs. immutable
 - Sorted vs. unsorted
 - Accepts null or not
 - Accepts duplicates or not
 - Concurrency/thread-safe or not
 - ...

The philosophy of the Collections framework

- Powerful and general
- Small in size and conceptual weight
 - Only include fundamental operations
 - "Fun and easy to learn and use"

The `java.util.Collection<E>` interface

```
boolean      add(E e);
boolean      addAll(Collection<E> c);
boolean      remove(E e);
boolean      removeAll(Collection<E> c);
boolean      retainAll(Collection<E> c);
boolean      contains(E e);
boolean      containsAll(Collection<E> c);
void        clear();
int         size();
boolean      isEmpty();
Iterator<E> iterator();
Object[]    toArray();
E[]         toArray(E[] a);
```

Java Collections design decisions

- Collection represents group of elements
 - e.g. lists, queues, sets, stacks, ...
- No inherent concept of order or uniqueness
- Mutation is optional
 - May throw UnsupportedOperationException
 - Documentation describes whether mutation is supported
- Maps are not Collections
- Helper functions (sort, search, copy, ...) in a separate Collections class

The `java.util.List<E>` interface

- Defines order of a collection
 - Uniqueness unspecified
- Extends `java.util.Collection<E>`:

```
boolean add(int index, E e);
E      get(int index);
E      set(int index, E e);
int    indexOf(E e);
int    lastIndexOf(E e);
List<E> sublist(int fromIndex, int toIndex);
```

The `java.util.Set<E>` interface

- Enforces uniqueness of each element in collection
- Extends `java.util.Collection<E>`:
 //adds invariant (textual specification) only
- The Marker Interface design pattern
 - Problem: You want to define a behavioral constraint not enforced at compile time.
 - Solution: Define an interface with no methods, but with additional invariants as a Javadoc comment or JML specification.

The `java.util.Queue<E>` interface

- Additional helper methods only
- Extends `java.util.Collection<E>`:

```
boolean add(E e);      // These three methods  
E      remove();      // might throw exceptions  
E      element();
```

```
boolean offer(E e);  
E      poll();        // These two methods  
E      peek();        // might return null
```

- Aside: Is `Queue<E>` a behavioral subtype?

The `java.util.Map<K,V>` interface

- Map of keys to values; keys are unique
- Does not extend `java.util.Collection<E>`

```
V      put(K key, V value);
V      get(Object key);
V      remove(Object key);
boolean containsKey(Object key);
boolean containsValue(Object value);
void    putAll(Map<K,V> m);
int     size();
boolean isEmpty();
void    clear();
Set<K>          keySet();
Collection<V>    values();
Set<Map.Entry<K,V>> entrySet();
```

One problem: Java arrays are not Collections

- To convert a Collection to an array

- Use the `toArray()` method

```
List<String> arguments = new LinkedList<String>();  
... // puts something into the list  
String[] arr = (String[]) arguments.toArray();  
String[] brr = arguments.toArray(new String[0]);
```

- To view an array as a Collection

- Use the `java.util.Arrays.asList()` method

```
String[] arr = {"foo", "bar", "baz", "qux"};  
List<String> arguments = Arrays.asList(arr);
```

What design pattern is this?

One problem: Java arrays are not Collections

- To convert a Collection to an array

- Use the `toArray()` method

```
List<String> arguments = new LinkedList<String>();  
... // puts something into the list  
String[] arr = (String[]) arguments.toArray();  
String[] brr = arguments.toArray(new String[0]);
```

- To view an array as a Collection

- Use the `java.util.Arrays.asList()` method

```
String[] arr = {"foo", "bar", "baz", "qux"};  
List<String> arguments = Arrays.asList(arr);
```

- The Adapter design pattern

- `Arrays.asList()` returns an adapter from an array to the `List` interface

Java Collections as a framework

- You can write specialty collections
 - Custom representations and algorithms
 - Custom behavioral guarantees
 - e.g., file-based storage
- JDK built-in algorithms (e.g. all helper functions in Collections) would then be calling your collections code

The abstract `java.util.AbstractList<T>`

```
abstract T    get(int i);                      // Template Method.  
abstract int   size();                        // Template Method.  
boolean      set(int i, E e);                 // set add remove are  
boolean      add(E e);                       // pseudo-abstract  
boolean      remove(E e);                    // Template Methods.  
boolean      addAll(Collection<E> c);  
boolean      removeAll(Collection<E> c);  
boolean      retainAll(Collection<E> c);  
boolean      contains(E e);  
boolean      containsAll(Collection<E> c);  
void        clear();  
boolean      isEmpty();  
Iterator<E> iterator();  
Object[]    toArray()  
E[]         toArray(E[] a);  
...  
...
```

Traversing a Collection

- Old-school Java for loop for ordered types

```
List<String> arguments = ...;
for (int i = 0; i < arguments.size(); ++i) {
    System.out.println(arguments.get(i));
}
```

- Modern standard Java for-each loop

```
List<String> arguments = ...;
for (String s : arguments) {
    System.out.println(s);
}
```

- Works for every implementation of Iterable

```
public interface Iterable<E> {
    public Iterator<E> iterator();
}
```

The Iterator interface

```
public interface java.util.Iterator<E> {  
    boolean hasNext();  
    E next();  
    void remove(); // removes previous returned item  
} // from the underlying collection
```

- To use, e.g.:

```
List<String> arguments = ...;  
for (Iterator<String> it = arguments.iterator();  
     it.hasNext(); ) {  
    String s = it.next();  
    System.out.println(s);  
}
```

The Iterator design pattern

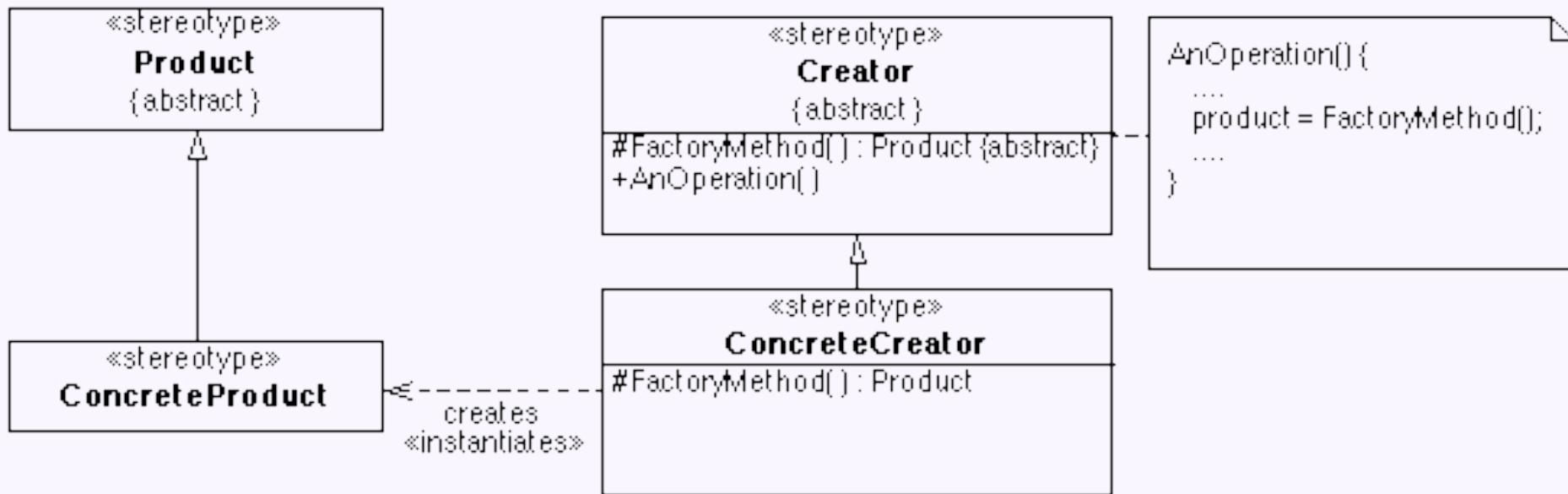
- Provide a strategy to uniformly access all elements of a container in a sequence
 - Independent of the container implementation
 - Ordering is unspecified, but every element visited once
- Design for change, information hiding
 - Hides internal implementation of container behind uniform explicit interface
- Design for reuse, division of labor
 - Hides complex data structure behind simple interface
 - Facilitates communication between parts of the program

Creating Iterators

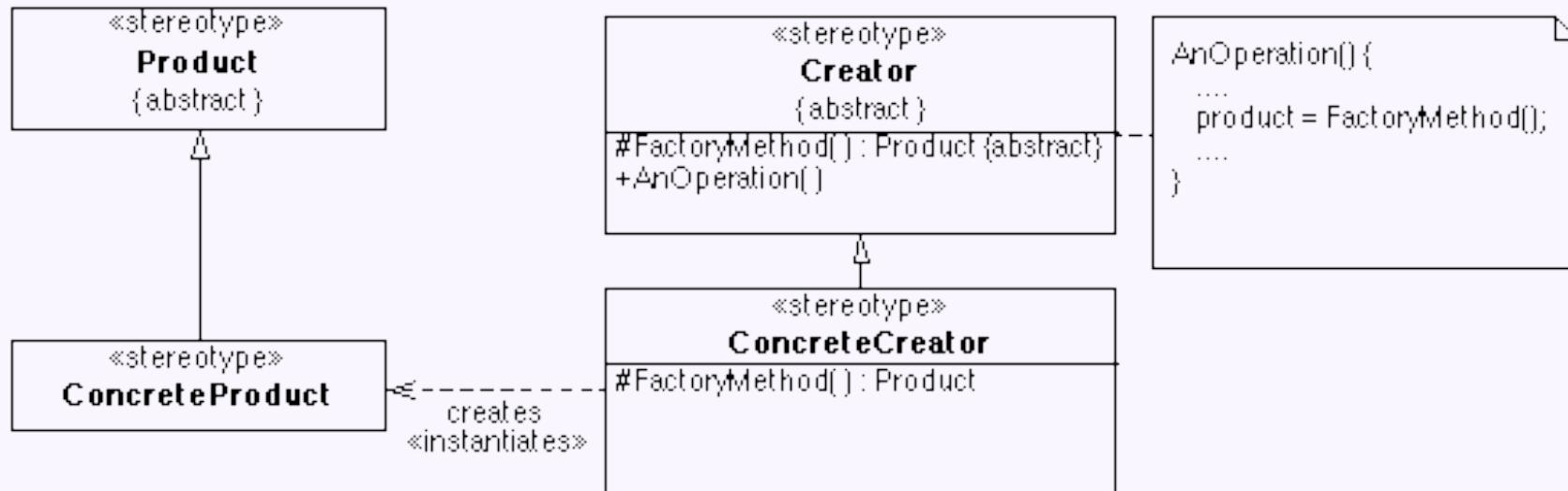
```
public interface Collection<E> {  
    boolean      add(E e);  
    boolean      addAll(Collection<E> c);  
    boolean      remove(E e);  
    boolean      removeAll(Collection<E> c);  
    boolean      retainAll(Collection<E> c);  
    boolean      contains(E e);  
    boolean      containsAll(Collection<E> c);  
    void         clear();  
    int          size();  
    boolean      isEmpty();  
    Iterator<E> iterator(); ←  
    Object[]     toArray()  
    E[]          toArray(E[] a);  
    ...  
}
```

Defines an interface for creating an Iterator, but allows Collection implementation to decide which Iterator to create.

The Factory Method design pattern



The Factory Method design pattern



• Applicability

- A class can't anticipate the class of objects it must create
- A class wants its subclasses to specify the objects it creates

• Consequences

- Provides hooks for subclasses to customize creation behavior
- Connects parallel class hierarchies

A Pair Iterator example

```
public class Pair<E> implements Iterable<E> {  
    private final E first, second;  
    public Pair(E f, E s) { first = f; second=s; }  
    public Iterator<E> iterator() {  
        return new PairIterator();  
    }  
    private class PairIterator implements Iterator<E> {  
        private boolean seen1=false, seen2=false;  
        public boolean hasNext() { return !seen2; }  
        public E next() {  
            if (!seen1) { seen1=true; return first; }  
            if (!seen2) { seen2=true; return second; }  
            throw new NoSuchElementException();  
        }  
        public void remove() { throw new UnsupportedOperationException(); }  
    }  
    Pair<String> pair = new Pair<String>("foo", "bar");  
    for (String s : pair) { ... }  
}
```

Using a `java.util.Iterator<E>`: A warning

- The default Collections implementations are mutable...
- ...but their Iterator implementations assume the collection does not change while the Iterator is being used
 - You will get a `ConcurrentModificationException`
 - One way to fix:

```
List<String> arguments = ...;
for (Iterator<String> it = arguments.iterator();
     it.hasNext(); ) {
    String s = it.next();
    if (s.equals("Charlie"))
        arguments.remove("Charlie"); // runtime error
}
```

Sorting a Collection

- Use the `Collections.sort` method:

```
public static void main(String[] args) {  
    List<String> lst = Arrays.asList(args);  
    Collections.sort(lst);  
    for (String s : lst) {  
        System.out.println(s);  
    }  
}
```

- A hacky aside: abuse the `SortedSet`:

```
public static void main(String[] args) {  
    SortedSet<String> set =  
        new TreeSet<String>(Arrays.asList(args));  
    for (String s : set) {  
        System.out.println(s);  
    }  
}
```

Sorting your own types of objects

```
public interface Comparable<T> {  
    int compareTo(T o);  
}
```

- General contracts:

- a.compareTo(b) should return:
 - <0 if a is less than b
 - 0 if a and b are equal
 - >0 if a is greater than b
- Should define a total order:
 - If a.compareTo(b) < 0 and b.compareTo(c) < 0, then a.compareTo(c) should be < 0
 - If a.compareTo(b) < 0, then b.compareTo(a) should be > 0
- Should usually be consistent with .equals:
 - a.compareTo(b) == 0 iff a.equals(b)

Comparable objects – an example

```
public class Integer implements Comparable<Integer> {  
    private int val;  
    public Integer(int val) { this.val = val; }  
    ...  
    public int compareTo(Integer o) {  
        if (val < o.val) return -1;  
        if (val == o.val) return 0;  
        return 1;  
    }  
}
```

**Aside: Is this
the Template
Method pattern?**

Comparable objects – another example

- Make Name comparable:

```
public class Name {  
    private String first;  
    private String last;  
    public Name(String first, String last) { // should  
        this.first = first; this.last = last; // check  
    } // for null  
    ...  
}
```

- Hint: Strings implement Comparable<String>

Comparable objects – another example

- Make Name comparable:

```
public class Name implements Comparable<Name> {  
    private String first;  
    private String last;  
    public Name(String first, String last) { // should  
        this.first = first; this.last = last; // check  
    } // for null  
    ...  
    public int compareTo(Name o) {  
        int lastComparison = last.compareTo(o.last);  
        if (lastComparison != 0) return lastComparison;  
        return first.compareTo(o.first);  
    }  
}
```

Alternative comparisons

```
public class Employee implements Comparable<Employee> {  
    protected Name name;  
    protected int salary;  
    ...  
}
```

- What if we want to sort Employees by name, usually, but sometimes sort by salary?

Alternative comparisons

```
public class Employee implements Comparable<Employee> {  
    protected Name name;  
    protected int salary;  
  
    ...  
}
```

- What if we want to sort Employees by name, usually, but sometimes sort by salary?
- Answer: There's a Strategy design pattern interface for that

```
public interface Comparator<T> {  
    public int compare(T o1, T o2);  
    public boolean equals(Object obj);  
}
```

Tradeoffs

```
void sort(int[] list, String order) {  
    ...  
    boolean mustswap;  
    if (order.equals("up")) {  
        mustswap = list[i] < list[j];  
    } else if (order.equals("down")) {  
        mustswap = list[i] > list[j];  
    }  
    ...  
}
```

```
void sort(int[] list, Comparator cmp) {  
    ...  
    boolean mustswap;  
    mustswap = cmp.compare(list[i], list[j]);  
    ...  
}  
interface Comparator {  
    boolean compare(int i, int j);  
}  
class UpComparator implements Comparator {  
    boolean compare(int i, int j) { return i < j; } }  
  
class DownComparator implements Comparator {  
    boolean compare(int i, int j) { return i > j; } }
```

Writing a Comparator object

```
public class Employee implements Comparable<Employee> {  
    protected Name name;  
    protected int salary;  
    public int compareTo(Employee o) {  
        return name.compareTo(o.name);  
    }  
}  
  
public class EmpSalComp implements Comparator<Employee> {  
    public int compare (Employee o1, Employee o2) {  
        return o1.salary - o2.salary;  
    }  
    public boolean equals(Object obj) {  
        return obj instanceof EmpSalComp;  
    }  
}
```

Using a Comparator

- Order-dependent classes and methods take a Comparator as an argument

```
public class Main {  
    public static void main(String[] args) {  
        SortedSet<Employee> empByName = // sorted by name  
            new TreeSet<Employee>();  
  
        SortedSet<Employee> empBySal = // sorted by salary  
            new TreeSet<Employee>(new EmpSalComp());  
    }  
}
```

The `java.util.Collections` class

- Standard implementations of common algorithms
 - `binarySearch`, `copy`, `fill`, `frequency`, `indexOfSubList`,
`min`, `max`, `nCopies`, `replaceAll`, `reverse`, `rotate`, `shuffle`,
`sort`, `swap`, ...

```
public class Main() {  
    public static void main(String[] args) {  
        List<String> lst = Arrays.asList(args);  
        int x = Collections.frequency(lst, "Charlie");  
        System.out.println("There are " + x +  
                           " students named Charlie");  
    }  
}
```

The `java.util.Collections` class

- Helper methods in `java.util.Collections`:

```
static List<T> unmodifiableList(List<T> lst);
static Set<T> unmodifiableSet( Set<T> set);
static Map<K,V> unmodifiableMap( Map<K,V> map);
```

- e.g., Turn a mutable list into an immutable list
 - All mutable operations on resulting list throw an `UnsupportedOperationException`

- Similar for synchronization:

```
static List<T> synchronizedList(List<T> lst);
static Set<T> synchronizedSet( Set<T> set);
static Map<K,V> synchronizedMap( Map<K,V> map);
```

e.g., The UnmodifiableCollection class

```
public static <T> Collection<T> unmodifiableCollection(Collection<T> c)
    return new UnmodifiableCollection<>(c);
}

class UnmodifiableCollection<E>
    implements Collection<E>, Serializable {

    final Collection<E> c;

    UnmodifiableCollection(Collection<> c){this.c = c; }

    public int         size()                  {return c.size();}
    public boolean    isEmpty()                {return c.isEmpty();}
    public boolean    contains(Object o)      {return c.contains(o);}
    public Object[]   toArray()                {return c.toArray();}
    public <T> T[]     toArray(T[] a)        {return c.toArray(a);}
    public String     toString()               {return c.toString();}
    public boolean    add(E e) {throw new UnsupportedOperationException();}
    public boolean    remove(Object o) { throw new UnsupportedOperationException();}
    public boolean    containsAll(Collection<?> coll) { return c.containsAll(coll);}
    public boolean    addAll(Collection<? extends E> coll) { throw new UnsupportedOperationException();}
    public boolean    removeAll(Collection<?> coll) { throw new UnsupportedOperationException();}
    public boolean    retainAll(Collection<?> coll) { throw new UnsupportedOperationException();}
```

e.g., The UnmodifiableCollection class

```
public static <T> Collection<T> unmodifiableCollection(Collection<T> c)
    return new UnmodifiableCollection(c);
```

What design pattern is this?

```
class UnmodifiableCollection<E>
    implements Collection<E>, Serializable {

    final Collection<E> c;

    UnmodifiableCollection(Collection<E> c){this.c = c; }

    public int size() {return c.size();}
    public boolean isEmpty() {return c.isEmpty();}
    public boolean contains(Object o) {return c.contains(o);}
    public Object[] toArray() {return c.toArray();}
    public <T> T[] toArray(T[] a) {return c.toArray(a);}
    public String toString() {return c.toString();}
    public boolean add(E e) {throw new UnsupportedOperationException();}
    public boolean remove(Object o) { throw new UnsupportedOperationException();}
    public boolean containsAll(Collection<?> coll) { return c.containsAll(coll);}
    public boolean addAll(Collection<? extends E> coll) { throw new UnsupportedOperationException();}
    public boolean removeAll(Collection<?> coll) { throw new UnsupportedOperationException();}
    public boolean retainAll(Collection<?> coll) { throw new UnsupportedOperationException();}
```

e.g., The UnmodifiableCollection class

```
public static <T> Collection<T> unmodifiableCollection(Collection<T> c)
    return new UnmodifiableCollection<T>(c);
}
```

What design pattern is this?

```
class UnmodifiableCollection<E>
    implements Collection<E> {
    final Collection<E> c;
```

**UnmodifiableCollection
decorates Collection by
removing functionality...**

```
UnmodifiableCollection(Collection<E> c){this.c = c; }
public int size() {return c.size();}
public boolean isEmpty() {return c.isEmpty();}
public boolean contains(Object o) {return c.contains(o);}
public Object[] toArray() {return c.toArray();}
public <T> T[] toArray(T[] a) {return c.toArray(a);}
public String toString() {return c.toString();}
public boolean add(E e) {throw new UnsupportedOperationException();}
public boolean remove(Object o) { throw new UnsupportedOperationException();}
public boolean containsAll(Collection<?> coll) { return c.containsAll(coll);}
public boolean addAll(Collection<? extends E> coll) { throw new UnsupportedOperationException();}
public boolean removeAll(Collection<?> coll) { throw new UnsupportedOperationException();}
public boolean retainAll(Collection<?> coll) { throw new UnsupportedOperationException();}
```

Summary

- Collections as reusable and extensible data structures
 - design for reuse
 - design for change
- Iterators to abstract over internal structure
- Decorator to attach behavior at runtime
- Template methods and factory methods to support behavior changes in subclasses
- Adapters to bridge between implementations
- Strategy pattern for sorting