Generic types and parametric polymorphism

Lecture 8
CS 2112 – Spring 2012

Generic Types

- When using a collection (e.g., `LinkedList, HashSet, HashMap`), we generally have a single type T of elements that we store in it (e.g., `Integer, String`)
- Before Java 5, when extracting an element, had to cast it to T before we could invoke T's methods
- Compiler could not check that the cast was correct at compile-time, since it didn't know what T was
- Inconvenient and unsafe, could fail at runtime

- Generics provide a way to communicate T, the type of elements in a collection, to the compiler
  - Compiler can check that you have used the collection consistently
  - Result: safer and more-efficient code

Example

old

```
//removes all 4-letter words from c
//elements must be Strings
static void purge(Collection c) {
  Iterator i = c.iterator();
  while (i.hasNext()) {
    if (((String)i.next()).length() == 4)
      i.remove();
}}
```

new

```
//removes all 4-letter words from c
static void purge(Collection<String> c) {
  Iterator<String> i = c.iterator();
  while (i.hasNext()) {
    if (i.next().length() == 4)
      i.remove();
}}
```


Another Example

old

```
Map grades = new HashMap();
grades.put("John", new Integer(67));
grades.put("Jane", new Integer(88));
grades.put("Fred", new Integer(72));
Integer x = (Integer)grades.get("John");
sum = sum + x.intValue();
```

new

```
Map<String, Integer> grades = new HashMap<String, Integer>();
grades.put("John", new Integer(67));
grades.put("Jane", new Integer(88));
grades.put("Fred", new Integer(72));
Integer x = grades.get("John");
sum = sum + x.intValue();
```

Type Casting

- The Java compiler determines that the cast is not necessary, based on the declared type
- In this example, `grades.get("John")` is known at compile time always to be an `Integer`

```
Map<String, Integer> grades = new HashMap<String, Integer>();
grades.put("John", new Integer(67));
grades.put("Jane", new Integer(88));
grades.put("Fred", new Integer(72));
Integer x = grades.get("John");
sum = sum + x.intValue();
```


Autoboxing

- Java 5 also introduced *autoboxing* and *auto-unboxing* of primitive types, so the example can be further simplified

```
Map<String,Integer> grades = new HashMap<String,Integer>();
grades.put("John",new Integer(67));
grades.put("Jane",new Integer(88));
grades.put("Fred",new Integer(72));
Integer x = grades.get("John");
sum = sum + x.intValue();
```

```
Map<String,Integer> grades = new HashMap<String,Integer>();
grades.put("John", 67);
grades.put("Jane", 88);
grades.put("Fred", 72);
sum = sum + grades.get("John");
```


Using Generic Types

- <T> is read, "of T"
  - For example: `Stack<Integer>` is read, "Stack of Integer"
- The type annotation <T> informs the compiler that all extractions from this collection are of type T
- Specify type in declaration, can be checked at compile time
  - Can eliminate explicit casts
  - No need for the runtime check

Advantage of Generics

- Declaring `Collection<String> c` tells us something about the variable c (i.e., c holds only Strings)
  - This is true wherever c is used
  - The compiler checks this and won't compile code that violates this
- Without use of generic types, explicit casting would be necessary
  - A cast tells us something the programmer thinks is true at a single point in the code
  - The Java virtual machine checks whether the programmer is right only at runtime

Subtypes

`Stack<Integer>` is *not* a subtype of `Stack<Object>`

```
Stack<Integer> s = new Stack<Integer>();
s.push(new Integer(7));
Stack<Object> t = s; // gives compiler error
t.push("bad idea");
System.out.println(s.pop().intValue());
```

However, `Stack<Integer>` *is* a subtype of `Stack` (for backward compatibility with previous Java versions)

```
Stack<Integer> s = new Stack<Integer>();
s.push(new Integer(7));
Stack t = s;          // compiler allows this
t.push("bad idea");   // produces a warning
System.out.println(s.pop().intValue()); //runtime error!
```


Programming with Generic Types

```
public interface List<E> { // E is a type variable
   void add(E x);
   Iterator<E> iterator();
}

public interface Iterator<E> {
   E next();
   boolean hasNext();
   void remove();
}
```

- To use the interface `List<E>`, supply an actual type argument, e.g., `List<Integer>`
- All occurrences of the formal type parameter (`E` in this case) are replaced by the actual type argument (`Integer` in this case)

Wildcards

old

```
void printCollection(Collection c) {
  Iterator i = c.iterator();
  while (i.hasNext()) {
    System.out.println(i.next());
}}
```

bad

```
void printCollection(Collection<Object> c) {
  for (Object e : c) {
    System.out.println(e);
}}
```

good

```
void printCollection(Collection<?> c) {
  for (Object e : c) {
    System.out.println(e);
}}
```


Bounded Wildcards

```
static void sort (List<? extends Comparable> c) {
   ...
}
```

- Note that if we declared the parameter `c` to be of type `List<Comparable>` then we could not sort an object of type `List<String>` (even though String is a subtype of Comparable)
  - Suppose Java treated `List<String>` and `List<Integer>` as a subtype of `List<Comparable>`
  - Then, for instance, a method passed an object of type `List<Comparable>` would be able to store `Integer`s in our `List<String>`
- Wildcards let us specify exactly what types are allowed

Generic Methods

- Adding all elements of an array to a **`Collection`**

bad

```
static void a2c(Object[] a, Collection<?> c) {
  for (Object o : a) {
    c.add(o); // compile time error
}}
```

good

```
static <T> void a2c(T[] a, Collection<T> c) {
  for (T o : a) {
    c.add(o); // ok
}}
```

- See the online Java tutorial for more info on generics
  `http://download.oracle.com/javase/tutorial/java/generics/`

Generic Classes

```
public class Queue<T> extends AbstractBag<T> {

   private java.util.LinkedList<T> queue
      = new java.util.LinkedList<T>();

   public void insert(T item) {
      queue.add(item);
   }

   public T extract() throws java.util.NoSuchElementException {
      return queue.remove();
   }

   public void clear() {
      queue.clear();
   }

   public int size() {
      return queue.size();
   }
}
```


Generic Classes

```
public class InsertionSort<T extends Comparable<T>> {

   public void sort(T[] x) {

      for (int i = 1; i < x.length; i++) {
         // invariant is: x[0],...,x[i-1] are sorted
         // now find rightful position for x[i]
         T tmp = x[i];
         int j;
         for (j = i; j > 0 && x[j-1].compareTo(tmp) > 0; j--)
            x[j] = x[j-1];
         x[j] = tmp;
      }
   }
}
```


Java Collections Framework

- Collections: holders that let you store and organize objects in useful ways for efficient access
- Since Java 1.2, the package **`java.util`** includes interfaces and classes for a general collection framework
- Goal: conciseness
  - A few concepts that are broadly useful
  - Not an exhaustive set of useful concepts
- The collections framework provides
  - Interfaces (i.e., ADTs)
  - Implementations

JCF Interfaces and Classes

- Interfaces
  - `Collection`
  - `Set (no duplicates)`
  - `SortedSet`
  - `List (duplicates OK)`
  - `Map (i.e., Dictionary)`
  - `SortedMap`
  - `Iterator`
  - `Iterable`
  - `ListIterator`
- Classes
  - `HashSet`
  - `TreeSet`
  - `ArrayList`
  - `LinkedList`
  - `HashMap`
  - `TreeMap`

`java.util.Collection<E>` (an interface)

- `public int size();`
  - Return number of elements in collection
- `public boolean isEmpty();`
  - Return true iff collection holds no elements
- `public boolean add(E x);`
  - Make sure the collection includes x; returns true if collection has changed (some collections allow duplicates, some don't)
- `public boolean contains(Object x);`
  - Returns true iff collection contains x (uses equals( ) method)
- `public boolean remove(Object x);`
  - Removes a single instance of x from the collection; returns true if collection has changed
- `public Iterator<E> iterator();`
  - Returns an Iterator that steps through elements of collection

`java.util.Iterator<E>` (an interface)

- `public boolean hasNext();`
  - Returns true if the iteration has more elements
- `public E next();`
  - Returns the next element in the iteration
  - Throws `NoSuchElementException` if no next element
- `public void remove();`
  - The element most recently returned by `next()` is removed from the underlying collection
  - Throws `IllegalStateException` if `next()` not yet called or if `remove()` already called since last `next()`
  - Throws `UnsupportedOperationException` if `remove()` not supported

Additional Methods of `Collection<E>`

- `public Object[] toArray()`
  - Returns a new array containing all the elements of this collection
- `public <T> T[] toArray(T[] dest)`
  - Returns an array containing all the elements of this collection; uses dest as that array if it can
- Bulk Operations:
  - `public boolean containsAll(Collection<?> c);`
  - `public boolean addAll(Collection<? extends E> c);`
  - `public boolean removeAll(Collection<?> c);`
  - `public boolean retainAll(Collection<?> c);`
  - `public void clear();`

java.util.Set<E> (an interface)

- **Set** extends **Collection**
  - **Set** inherits all its methods from **Collection**
- A **Set** contains no duplicates
  - If you attempt to **add()** an element twice then the second **add()** will return false (i.e., the **Set** has not changed)
- Write a method that checks if a given word is within a **Set** of words
- Write a method that removes all words longer than 5 letters from a **Set**
- Write methods for the union and intersection of two **Set**s

Set Implementations

- **java.util.HashSet<E>** (a hashtable)
  - Constructors
    - public HashSet();
    - public HashSet(Collection<? extends E> c);
    - public HashSet(int initialCapacity);
    - public HashSet(int initialCapacity, float loadFactor);
- **java.util.TreeSet<E>** (a balanced BST [red-black tree])
  - Constructors
    - public TreeSet();
    - public TreeSet(Collection<? extends E> c);
    - ...

java.util.SortedSet<E> (an interface)

- **SortedSet** *extends* **Set**
- For a **SortedSet**, the **iterator()** returns the elements in sorted order
- Methods (in addition to those inherited from **Set**):
  - **public E first();**
    - Returns the first (lowest) object in this set
  - **public E last();**
    - Returns the last (highest) object in this set
  - **public Comparator<? super E> comparator();**
    - Returns the **Comparator** being used by this sorted set if there is one; returns null if the natural order is being used
  - …

java.lang.Comparable<T> (an interface)

- **public int compareTo(T x);**
  - Returns a value (< 0), (= 0), or (> 0)
    - (< 0) implies **this** is before **x**
    - (= 0) implies **this.equals(x)** is true
    - (> 0) implies **this** is after **x**
- Many classes implement **Comparable**
  - **String**, **Double**, **Integer**, **Char**, **java.util.Date**,…
  - If a class implements **Comparable** then that is considered to be the class's *natural ordering*

`java.util.Comparator<T>` (an interface)

- `public int compare(T x1, T x2);`
  - Returns a value (< 0), (= 0), or (> 0)
    - (< 0) implies `x1` is before `x2`
    - (= 0) implies `x1.equals(x2)` is true
    - (> 0) implies `x1` is after `x2`
- Can often use a `Comparator` when a class's natural order is not the one you want
  - `String.CASE_INSENSITIVE_ORDER` is a predefined `Comparator`
  - `java.util.Collections.reverseOrder()` returns a `Comparator` that reverses the natural order

`SortedSet` Implementations

- `java.util.TreeSet<E>`
  - constructors:
    - `public TreeSet();`
    - `public TreeSet(Collection<? extends E> c);`
    - `public TreeSet(Comparator<? super E> comparator);`
    - ...
- Write a method that prints out a `SortedSet` of words in order
- Write a method that prints out a `Set` of words in order

`java.util.List<E>` (an interface)

- `List` extends `Collection`
- Items in a list can be accessed via their index (position in list)
- The `add()` method always puts an item at the end of the list
- The `iterator()` returns the elements in list-order
- Methods (in addition to those inherited from `Collection`):
  - `public E get(int index);`
    - Returns the item at position index in the list
  - `public E set(int index, E x);`
    - Places x at position index, replacing previous item; returns the previous item
  - `public void add(int index, E x);`
    - Places x at position index, shifting items to make room
  - `public E remove(int index);`
    - Remove item at position index, shifting items to fill the space;
    - Returns the removed item
  - `public int indexOf(Object x);`
    - Return the index of the first item in the list that equals x (x.equals())
  - …

List Implementations

- `java.util.ArrayList<E>` (an array; uses array-doubling)
  - Constructors
    - `public ArrayList();`
    - `public ArrayList(int initialCapacity);`
    - `public ArrayList(Collection<? extends E> c);`
- `java.util.LinkedList<E>` (a doubly-linked list)
  - Constructors
    - `public LinkedList();`
    - `public LinkedList(Collection<? extends E> c);`
- Both include some additional useful methods specific to that class

Efficiency Depends on Implementation

- `Object x = list.get(k);`
  - O(1) time for `ArrayList`
  - O(k) time for `LinkedList`

- `list.remove(0);`
  - O(n) time for `ArrayList`
  - O(1) time for `LinkedList`

- `if (set.contains(x)) ...`
  - O(1) expected time for `HashSet`
  - O(log n) for `TreeSet`