Introduction to Computation and Problem Solving

Class 32: The Java Collections Framework

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Goals

- To introduce you to the data structure classes that come with the JDK;
- To talk about how you design a *library* of related classes
- To review which data structures are the best tools for a variety of algorithmic tasks

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History

In the original version of the Java Development Kit, JDK 1.0, developers were provided very few data structures. These were:

- `Vector`
- `Stack`: which extended `Vector`
- `Hashtable`: very similar to our implementation of `HashMap`
- `Dictionary`: an abstract class that defined the interface and some functionality for classes that map keys to values. `Dictionary` served as the base class for `Hashtable`.
- `Enumeration`: was a simple version of our `Iterator` that allowed you to iterate over instances of `Hashtable` and `Vector`.

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The Java Collections Framework

- The Java designers realized that this set of data structures was inadequate.
- They prototyped a new set of data structures as a separate toolkit late in JDK 1.1, and then made it a formal part of the JDK in version 1.2.
- This later, fuller, better designed set of classes is called the Java Collections Framework.
- There is a good tutorial on its use at http://java.sun.com/docs/books/tutorial/collections/index.html.

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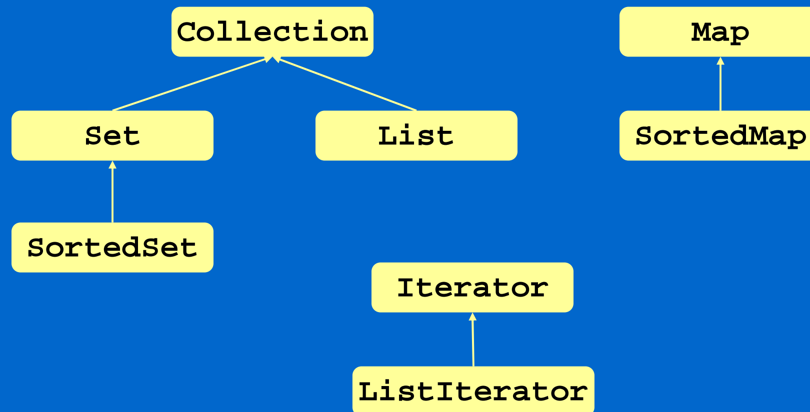
Collections Interfaces, 1



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Collections Interfaces, 2

- `Collection`: is the most basic interface; it has the functionality of an unordered list, aka a *multi-set*, a set that doesn't not check for duplicates.
- `Set`: adds set semantics; that is, it won't allow duplicate members.
- `List`: adds list semantics; that is, a sense of order and position
- `SortedSet`: adds order to set semantics; our binary search tree that just consisted of keys without values could be implemented as a `SortedSet`

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Collections Interfaces, 3

- `Map`: the basic interface for data structures that map keys to values; it uses an inner class called an `Entry`
- `SortedMap`: a map of ordered keys with values; our binary search tree is a good example
- `Iterator`: our Iterator except that it is *fail fast*; it throws a `ConcurrentModificationException` if you use an instance after the underlying `Collection` has been modified.
- `ListIterator`: a bidirectional iterator.

Collection Implementations

- The Java designers worked out the architecture of interfaces independently of any data structures. In a second stage they created a number of concrete implementations of the interfaces based on slightly more sophisticated versions of the data structures that we have been studying:
  - *Resizable Array*: similar to the technique used for our Stack implementation.
  - *Linked List*: uses a doubly, not singly, linked list.
  - *Hash Table*: very similar to our implementation except that it will grow the number of slots once the load factor passes a value that can be set in the constructor.
  - *Balanced Tree*: similar to our binary search tree implementation but based on the more sophisticated Red-Black tree that rebalances the tree after some operations.

Collection Implementations, 2

		Implementations			
		Hash Table	Resizable Array	Balanced Tree	Linked List
Inter-faces	*List*		`Array-List`		`Linked-List`
	Set	`HashSet`			
	Sorted Set			`TreeSet`	
	Map	`HashMap`			
	Sorted Map			`TreeMap`	

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Collection Implementations, 3

- Notice the gaps. There is no list based on a hash table. Why? What about a set implementation based on a linked list?
- The goal of the Java designers was to create a small set of implementations to get users started, not an exhaustive set.
- They expect that developers will extend the set of collection classes just as they expect that developers will add more stream classes.
- The most important part of the collection design was the architecture of interfaces. That's why they called it a *framework.*

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Implementation Choices

- Be careful of implementation choices. Not all the implementations are going to be efficient at all their operations.
- For instance, an `ArrayList` will allow you to remove its first element by calling remove(0). We already know this will be particularly inefficient.
- You can also iterate over a `LinkedList`, l, using the following code, but once again it will be very inefficient. Why?

```
for ( int i = 0; i < l.size(); i++ )  {
   Object o = l.get( i );
   // do what you need with o
}
```

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`Collection` Interface

```
public interface Collection<E> {
   // Query Operations
   int size();
   boolean isEmpty();
   boolean contains(Object o);
   boolean containsAll(Collection c);
   Iterator<E> iterator();
   Object[] toArray();
   <T> T toArray(T t[]);
   boolean equals(Object o);
   int hashCode();
```

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`Collection` Interface, 2

```
  // Modification Operations
  boolean add(E e);
  boolean remove(E e);
  boolean addAll(Collection<? extends E> c);
  boolean removeAll(Collection c);
  boolean retainAll(Collection c);
  void clear();
}
```

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Bulk Operations

- Note the *bulk* operations. All the interfaces derived from `Collection` support them:
  - `boolean containsAll( Collection c )`
  - `boolean addAll( Collection c )`
  - `boolean removeAll( Collection c )`
  - `boolean retainAll( Collection c )`
- `containsAll()` returns true if the target of the method contains all the elements in the argument collection. The other three methods return true if the operation changes the target collection.

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Bulk Constructors

All `Collection` (`Map`) implementations support at least two constructors.

- a default constructor that creates an empty `Collection` (`Map`) of the appropriate type, and
- a constructor that takes a `Collection` (`Map`) argument that creates a `Collection` (`Map`) of the appropriate type that contains references to all the objects in the `Collection` (`Map`) supplied as the argument.

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Array Operations

- All `Collection` implementations also possess a method with the signature:

```
Object [] toArray()
```

  which returns the contents of the collection in an appropriately sized array.

- A variant

```
<T> T[] toArray(T t[]);
```

  returns all the elements of the collection in array `t[]` itself or an appropriately sized array of the same type. All the elements in the Collection must be of type T.

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Array Examples

- `Collection c = new HashSet();`
  `// put Strings in c`
  `String[] s = c.toArray(new String[0]);`
  returns all elements of `c` in an array of `String`s.
- Note this is evil:
  `c.add( new Integer(42) );`
  `String[] s = c.toArray(new String[0]);`
  You will get an `ArrayStoreException`.
- `Collection c = new HashSet();`
  `// if c contains only Strings`
  `String[] s = (String[]) c.toArray( );`

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`List` Interface

```
public interface List<E> extends Collection<E> {
  // adds the following to Collection
  boolean addAll(int index,
                 Collection<? extends E> c);
  E get(int index);
  E set(int index, E element);
  void add(int index, E element);
  E remove(int index);
  int indexOf(Object o);
  int lastIndexOf(Object o);
  ListIterator<E> listIterator();
  ListIterator<E> listIterator(int index);
  List<E> subList(int fromIndex, int toIndex);
}
```

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Views

- Several of the interfaces also support *view* operations. In a view operation, a collection returns another collection that provides a specialized and usually partial view of its contents. A good example is

```
List subList( int from, int to )
```

- This method returns a second list that starts with the `from`'*th* element of the parent list and ends just before the `to`'*th* element. But the returned sublist is not a copy. It remains part of the original list.
- As an example, an elegant way to delete the 4th through 10th elements of a list is the following:

```
myList.subList( 3, 10 ).clear();
```

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`Set` Interface

```
public interface Set extends Collection {
  // has the same methods as Collection
  // but with stricter semantics,
  // no duplicate elements
}
```

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SortedSet Interface

```
public interface SortedSet<E> extends Set {
  // adds the following to Set
  Comparator comparator();
  SortedSet<E> subSet(E fromElement,
                      E toElement);
  SortedSet<E> headSet(E toElement);
  SortedSet<E> tailSet(E fromElement);
  E first();
  E last();
}
```

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Iterator Interface

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

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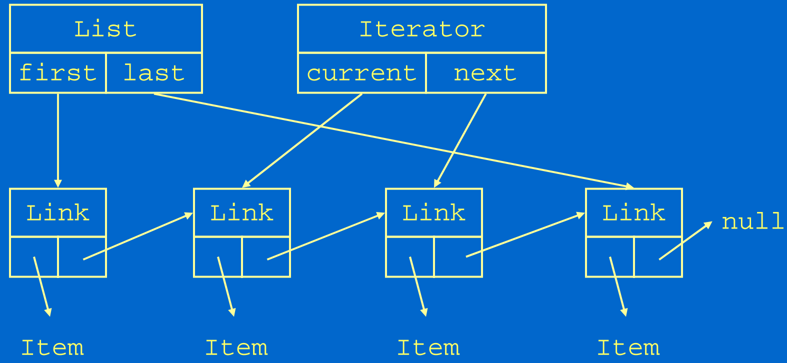
`ListIterator` Interface

```
public interface ListIterator<E>
  extends Iterator<E> {
  // adds the following to Iterator
  boolean hasPrevious();
  E previous();
  int nextIndex();
  int previousIndex();
  void set(E o);
  void add(E o);
}
```


Concurrent Modification

- Iterators have to keep references to the underlying data structure to maintain their sense of current position.
- Thought experiment:
  - create a LinkedList, add elements, get an iterator, advance it
  - now using a method in the list not the iterator, delete the iterator's next item
  - now call next() on the iterator
  - what goes wrong?
- Any time you create an iterator, modify the underlying collection, and then use the iterator, you will get a `ConcurrentModificationException`.
- How do you think they implement the check?

Concurrent Modification, Before



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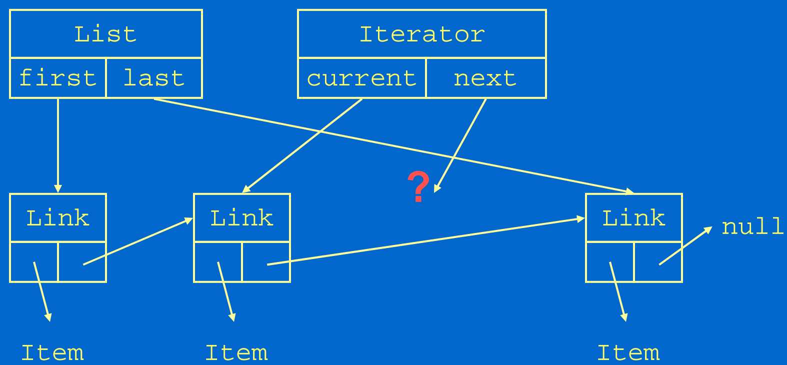
Concurrent Modification, After



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Map Interface

```
public interface Map<K, V> {
  // Query Operations
  int size();
  boolean isEmpty();
  boolean containsKey(K key);
  boolean containsValue(V value);
  V get(K key);
```

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Map Interface, 2

```
  // Modification Operations
  V put(K key, V value);
  V remove(K key);
  void putAll(Map<? extends K, ? extends V> t);
  void clear();
  // Views
  public Set<K> keySet();
  public Collection<V> values();
  public Set<Map.Entry<K, V>> entrySet();
  boolean equals(Object o);
  int hashCode();
```

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Nested `Map.Entry` Interface

```
public interface Entry<K, V> {
    K getKey();
    V getValue();
    V setValue(V value);
    boolean equals(Object o);
    int hashCode();
  }
}
```

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`Map` Views

- `Map`s also provide views. In fact they are crucial because a `Map` does not provide an `iterator()` method.
- They are two separate idioms for iterating over a Map, depending on whether you want to iterate over the keys or the values:

```
Map<K, V> m = ...;
// iterates over keys
for (Iterator<K> i=m.keySet().iterator();
i.hasNext();)
{...}
// iterates over values
for (Iterator<V> i=m.values().iterator();
i.hasNext();)
{...}
```

- In the second example, `values()` returns a Collection, not a Set, because the same value can occur multiple times in a map while a key must be unique.

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`SortedMap` Interface

```
public interface SortedMap<K, V>
      extends Map<K, V> {
  // adds the following to Map
  Comparator comparator();
  SortedMap<K, V> subMap(K fromKey, K toKey);
  SortedMap<K, V> headMap(K toKey);
  SortedMap<K, V> tailMap(K fromKey);
  K firstKey();
  K lastKey();
}
```


Optional Operations

- Not all implementations implement all the operations in an interface. The documentation makes it clear whether a particular implementation implements a given method. If it doesn't, it throws an `UnsupportedOperationException` (unchecked).
- At first, this just seems perverse, but the goal is to provide more flexibility. Imagine a program where you want to maintain a master index in which you want a normal user to be able to look up entries but only a privileged user to add entries to the index. The index could be implemented as a `SortedMap`, but then how could you keep an arbitrary user from adding and deleting entries? The answer is to subclass `SortedMap` and override each method you wanted to forbid with a simple method that throws an `UnsupportedOperationException`.

Algorithms

- The `Collections` class contains implementations of a number of useful algorithms implemented as `static` methods that take a `List` or sometimes a more general `Collection` as the target of the algorithm.
- Algorithms include `sort()`, `reverse()`, `min()`, `max()`, `fill(Object o)`, etc.

```
static void sort( List l, Comparator c )
static void fill( List l, Object o )
```

- There is a similar class `Arrays`, which implements most of the same algorithms for arrays.

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Read-Only Collections

`Collections` can also produce unmodifiable (read only) views of all types of collections that will throw an `UnsupportedOperationException` on any write operation:

```
public static Collection
  unmodifiableCollection(Collection c);
public static Set unmodifiableSet(Set s);
...
```

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