The Collections Framework

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Generics

A generic is a type (class/interface) parameterized over another type.

```
// T is a type parameter
public class Box<T>
{
  private T t;
  public void set(T t) { this.t = t; }
  public T get() { return t; }
}
```

Objects of type `Box<`T`>` encapsulate values of some type T.

Type Instantation

A generic is to be instantiated before use.

```
Box<String> sbox = new Box<String>();
sbox.set("text");
String s = sbox.get();

Box<Integer> ibox = new Box<Integer>();
ibox.set(5);        // autoboxing:   ibox.set(new Integer(5));
int i = ibox.get(); // autounboxing: int i = ibox.get().intValue();
```

The instantiation type must be a class (not a primitive type).

Generic Interfaces

Also interfaces may be generic.

```
public interface Pair<A,B>
{
  public A getFirst();
  public B getSecond();
}
```

A generic may also have multiple parameters.

Generic Interfaces (Continued)

```
public class PairClass<A,B> implements Pair<A,B>
{
  private A first;
  private B second;

  public PairClass(A first, B second)
  { this.first = first; this.second = second; }

  public A getFirst() { return first; }
  public B getSecond() { return second; }
}

Pair<String,Integer> p = new PairClass<String,Integer>("key", 7);
String s = p.getFirst();
int i = p.getSecond(); // autounboxing
```

Implementation of Generics

Java implements generics by "type erasure".

- JVM only represents the "raw type" of a generic Box<T>.
  - Java: multiple instances Box<String> and Box<Integer>.
  - JVM: single raw type Box with T set to Object.
- No runtime information about the instantiation of T.
  - It is illegal to create an instance of T.

```
public class Generic<T>
{ public void method() { T x = new T(); } // illegal }
```

  - It is illegal to create an array of parameterized types.

```
Box<Integer>[] array = new Box<Integer>[10]; // illegal
```

However, we may create collections of parameterized types.

The Collections Framework

A library for the uniform processing of multiple types of "containers".

- Three kinds of entities:
  - Interfaces: abstract data types that denote the collections.
  - Implementations: classes that provide concrete implementations for the interfaces.
  - Algorithms: methods that operate on interfaces independently of their implementation.
- Two kinds of interfaces and associated classes:
  - Collections: based on (interfaces derived from) interface `Collection`<E>; objects represent certain kinds of "collections" of "elements" of type E.
    - Lists, sets, queues/deques.
  - Maps: based on interface `Map`<K,V>; objects represent "maps" of "keys" of type K to "values" of type V.

We are now going to investigate both "collections" and "maps".

Collections

```
public interface Collection<E> extends Iterable<E> {
  boolean add(E e);                  // add e to this collection
  boolean addAll(Collection<E> c); // add all elements of c
  void clear();                      // make collection empty
  boolean contains(Object o);        // is o in this collection?
  boolean containsAll(Collection<E> c); // are all elems of c in this?
  boolean isEmpty();                 // is this collection empty?
  boolean remove(Object o);          // remove o from this collection
  boolean removeAll(Collection<E> c); // remove all elems of c
  int size();                        // number of elements
}

Collection<String> c = ...
for (String e : c) System.out.println(e);
```

We may iterate over all collections.

Lists

```
public interface List<E> extends Collection<E> {
  E get(int index);              // get element at index >= 0
  E set(int index, E element); // set element at index >= 0
  void add(int index, E element); // insert element at index >= 0
  int indexOf(Object o);      // index of first occurrence of o (or -1)
  int lastIndexOf(Object o); // index of last occurrence of o (or -1)
  List<E> subList(int from, int to); // sublist view of range [from,to[
}

String[] a = new String[...];
List<String> l = Arrays.asList(a);
...
l.subList(from, to).clear();
```

The type of ordered collections whose elements can be accessed by indices; conversion from arrays to lists (and vice versa) are possible.

List Implementations

```
// implementation by an array
public class ArrayList<E> extends ... implements List<E>, ... {
  public ArrayList();
  public ArrayList(Collection<E> c);
  ...;
}
// implementation by a linked list
public class LinkedList<E> extends ... implements List<E>, ... {
  public LinkedList();
  public LinkedList(Collection<E> c);
  ...;
}

Collection<String> c = ...;
List<String> list = new ArrayList<String>(c);
```

Arbitrary collections may be converted to lists.

Sets

```
public interface Set<E> extends Collection<E> {  ... }

// implementation by a hash table
public class HashSet<E> extends ... implements Set<E>, ... {
  public HashSet();
  public HashSet(Collection<E> c);
  ...;
}

// implementation by a tree
public class TreeSet<E> extends ... implements Set<E>, ... { ... }

// implementation by a hash table and a linked list
public class LinkedHashSet<E> extends ... implements Set<E>, ... { ... }
```

The type of unordered collections with three core implementations.

Set Implementations

- `HashSet<`E`>`
  - Hash table, i.e., array that stores every element at a position computed from the element by application of a "hash function" that maps the elements to an integer (the "hash code").
  - Very fast but with unpredictable iteration order.
  - E must overwrite `int hashCode()` such that "equal" elements yield the same hash codes.
- `TreeSet<`E`>`
  - Binary tree, i.e., dynamic data structure that generalizes linked lists in that every node has two successor nodes.
  - Slower but with natural iteration order (e.g. integers in increasing order).
  - E must implement interface `Comparable`, i.e., provide a method `int compareTo(`E `x)`.
- `LinkedHashSet<`E`>`
  - Combination of a hash table and a linked list to which new elements are added.
  - Fast and iteration returns elements in insertion order.
  - E must overwrite `int hashCode()` such that "equal" elements yield the same hash codes.

Example

```
Collection<String> c = ...;
Set<String> set = new TreeSet<String>(c);
for (String s : set) System.out.println(s);
```

Prints all strings in a collection in alphabetic order (with duplicates removed).

Queues and Deques

```
public interface Queue<E> extends Collection<E> {
  public E remove();  // retrieve and remove head
  public E element(); // retrieve head without removing it
}

public interface Deque<E> extends Queue<E> {
  public addFirst(E e);  // add e to head
  public E removeLast(); // retrieve and remove tail
  public E getLast();    // retrieve tail without removing it
}
```

In a queue; elements are added to one end and removed from the other; in a deque ("doubly-ended queue"), elements can be added/removed to/from either end.

Queue and Dequeue Implementations

```
// implementation by an array
public class ArrayDeque<E> extends ... implements Deque<E>, ...
{
  public ArrayDeque();
  public ArrayDeque(Collection<E> c);
  ...;
}

// implementation by a linked list
public class LinkedList<E> extends ... implements List<E>, Deque<E>, ...
{
  public LinkedList();
  public LinkedList(Collection<E> c);
  ...;
}
```

Example

```
int n = ... ;
Queue<Integer> queue = new LinkedList<Integer>();
for (int i = 0; i < n; i++)
  queue.add(i);
while (!queue.isEmpty())
{
  int i = queue.remove();
  System.out.println(i);
}
```

Add n integers $0, \ldots, n-1$ to a queue and print them out in the order in which they were inserted.

Maps

```
public interface Map<K,V> {
  public V put(K key, V val); // maps key to value, returns previous value (or null)
  public V get(K key);        // returns value to which key is mapped (or null)
  ...

  // set of keys, collection of values, set of key/value pairs
  public Set<K> keySet();
  public Collection<V> values();
  public Set<Entry<K,V>> entrySet();

  public static interface Entry<K,V> { // the type of a key/value pair
    public K getKey();
    public V getValue();
  }
}
```

Access to values via keys or by iterating over the map elements.

Map Implementations

```
// implementation by a hash table
public class HashMap<K,V> extends ... implements Map<K,V>, ... {
  public HashMap();
  public HashMap(Map<K,V> m);
}
// implementation by a tree
public class TreeMap<K,V> extends ... implements Map<K,V>, ... {
  public TreeMap();
  public TreeMap(Map<K,V> m);
}
// implementation by a hash table and a linked list
public class LinkedHashMap<K,V> extends ... implements Map<K,V>, ... {
  public LinkedHashMap();
  public LinkedHashMap(Map<K,V> m);
}
```

Same properties as the corresponding `List<`E`>` implementations.

Example

```
// maps words to number of occurrences in their text
Map<String,Integer> map = new TreeMap<String,Integer>();

// reads words from individual lines and puts them in map
while (true) {
  String word = Input.readString();
  if (!Input.isOkay()) break;
  Integer count = map.get(word);
  if (count == null) map.put(word, 1);
  else map.put(word, count+1);
}

// prints words and their occurrences in lexicographic order
for (Map.Entry<String,Integer> entry : map.entrySet())
  System.out.println(entry.getKey() + ":" + entry.getValue());

... // to be continued
```

Generic Methods

```
public interface Collection<E> extends Iterable<E>
{
   ...
   <T> T[] toArray(T[] a); // copy this collection to a
}

// copy elements of collection c to array a
Collection<String> c = ...
String[] a = c.toArray(new String[c.size()]);
```

Example of a generic method parameterized over types.

Generic Methods

```
package java.util;
public class Collections {
  ...
  public static <T> boolean addAll(Collection<T> c, T[] a);
}

// add all elements of array a to list l
String[] a = new String[...];
...
List<String> l = new LinkedList<String>();
l.add("word");
Collections.addAll(l, a);
```

Operations that provide a bridge between collections and arrays.

Algorithms

Generic methods in class `java.util.Collections`.

```
// reverses the order of the elements in the list
public static <T> void reverse(List<T> list);

// replaces all elements of the list by the denoted value
public static <T> void fill(List<T> list, T value);

// copies all elements from src into dest replacing original elements
// if dest is longer than src, the remaining elements remain unchanged
public static <T> void fill(List<T> dest, List<T> src);

// swaps in list elements at position i and j
public static <T> void swap(List<T> list, int i, int j);
```

Algorithms

```
// returns position of key in list sorted according to natural order of T
public static <T> int binarySearch(List<T> list, T key);

// returns position of key in list T sorted according comparator c
public static <T> int binarySearch(List<T> list, T key, Comparator<T> c);

// sorts list in ascending order according to the natural order of T
public static <T> void sort(List<T> list);

// sorts list in ascending order according to comparator c
public static <T> void sort(List<T> list, Comparator<T> c);

public interface Comparator<T> {
  // returns -1, 0, 1, if o1 is less than, equal, or greater than o2
  public int compare(T o1, T o2);
}
```

Example

```
public class GreaterCounter
  implements Comparator<Map.Entry<String,Integer>>
{
  // returns -1, if entry1 has a greater counter than entry2
  public int compare(Map.Entry<String,Integer> entry1,
    Map.Entry<String,Integer> entry2)
  {
    Integer value1 = entry1.getValue();
    Integer value2 = entry2.getValue();
    return value2.compareTo(value1);
  }
}
```

Comparing the values of map entries.

Example (Continued)

```
// maps words to number of occurrences in their text
Map<String,Integer> map = new TreeMap<String,Integer>();

... // example continued

// create duplicate of entry set as a list
List<Map.Entry<String,Integer>> entries =
  new ArrayList<Map.Entry<String,Integer>>(map.entrySet());

// sort list in descending order of the word counters
Collections.sort(entries, new GreaterCounter());

// print words in descending order of the number of their occurrences
for (Map.Entry<String,Integer> entry : entries)
  System.out.println(entry.getKey() + ":" + entry.getValue());
```