Chapter 14

Using Dynamic Data Structures

Lecture slides for:

Java Actually: A Comprehensive Primer in Programming

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Cengage Learning, 2008.

ISBN: 978-1-844480-933-2

`http://www.ii.uib.no/~khalid/jac/`

Modified: 16/2/19

Overview

Dynamic data structures

Abstract data types (ADTs)

Dynamic strings: `StringBuilder`

Generic types

Collections and the interfaces `Collection`, `List` and `Set`:

- Dynamic arrays: `ArrayList`
- Sets: `HashSet`

Hashtables and the interface `Map`:

- Hashtables: `HashMap`

Subtyping with wildcard `?`

Generic methods

Dynamic data structures

- A *collection* is a data structure for storing data, e.g. an array defines a collection that stores elements of the same type and has fixed length.
- Dynamic data structures can grow and shrink as data is inserted into and retrieved from the structure.
  - The *contract* specifies *which* operations can be performed on the structure.
  - Clients do not need to know how it is implemented.
- Two most common operations:
  - Insertion: insert data into the structure.
  - Retrieval: extract data from the structure.
- Choice of data structure is largely contingent on how expensive it is to perform the insertion and lookup.

Abstract data types: ADT = data structure + contract

- Realization of *data abstractions* results in ADTs, i.e. the design of a new type with the corresponding *data representation* and *operations*.
- In Java, classes are ADTs.

Dynamic strings: `StringBuilder` class

- The contents of a `String` object *cannot* be changed, i.e., the *state* can only be read.
- Java has a predefined class `StringBuilder` to handle *sequences of characters that can be changed*, and where the character sequence can dynamically grow and shrink.
- An object of class `StringBuilder` keeps track of:
  - *size* (how many characters it contains at any given time), and
  - *capacity* (how many characters can be inserted in it before it becomes full)
    - If there is room for more characters, the capacity expands automatically.
- Choose the class `StringBuilder` instead of the `String` class if the sequence of characters is be changed frequently.
- Java has support for the *declaration*, *creation* and *use* of dynamic strings.

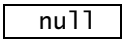
Declaration that creates a *reference* to a StringBuilder object:

```
StringBuilder variableName;
```

```
StringBuilder buffer1;
```

leads to the creation of a reference that can store the reference value of a `StringBuilder` object:

Navn: `buffer1`
Type: `ref(StringBuilder)`



Creating dynamic strings

- A `StringBuilder` object can be created by calling a `StringBuilder` *constructor* using the `new` operator.
- We can combine the declaration with the creation:

```
StringBuilder buffer = new StringBuilder(argument list);

// Create a StringBuilder object which has no characters and length 0,
// whose capacity is 16 characters:
StringBuilder nameBuffer = new StringBuilder();

// Create a StringBuilder object which has no characters and length 0,
// whose capacity is 10 characters:
StringBuilder addrBuffer   = new StringBuilder(10);

// Create a StringBuilder object from a string literal,
// whose capacity is string length + 16, i.e. 19 characters:
StringBuilder colourBuffer = new StringBuilder("red");

// Create a StringBuilder object from a String object.
StringBuilder strBuffer = new StringBuilder(str);
```


Operations on string buffers

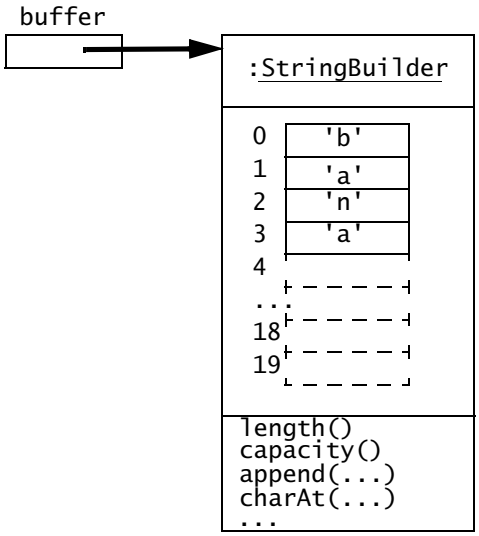
```
StringBuilder courseBuffer = new StringBuilder("Java is cool!");
```

Selectors for `StringBuilder` class:

- Each `StringBuilder` object has an instance method, `length()`, which returns the number of characters in the string buffer (*size*).
  - Method call `courseBuffer.length()` returns the number of characters in the string buffer, i.e. 13.
- Each `StringBuilder` object has an instance method, `capacity()`, which returns the number of characters that can be inserted into the string buffer before it expands to store more characters (*capacity*).
  - Method call `courseBuffer.capacity()` returns the number of characters that can be stored in the string buffer, i.e. 29.
- The method `charAt(int i)` returns the character given by index i the string buffer.
  - Method call `courseBuffer.charAt(2)` returns the character `'v'` at index 2 in the string buffer.
  - Start index is always 0.
  - Illegal index value results in a `StringIndexOutOfBoundsException`.

`StringBuilder` object

```
StringBuilder buffer = new StringBuilder("bana");
```



The `StringBuilder` object has 4 characters inserted, and room for 16 more - and can expand if necessary.

Operations on the string builders

Modifiers for `StringBuilder` class:

- Character can be inserted *anywhere* in the string builder.
  - Insertion may cause the other characters to be moved to make room for the new character.
  - The size is automatically adjusted on insertion.
- The over-loaded method `append()` can be used to add primitive values, `String` objects, arrays of characters and text representation of other objects at the *end* of the string builder.

```
String Builder buffer = new String Builder ("banana");
buffer.append("na"); // append a string to the end of the string builder: "banana"
buffer.append(42);   // append a number at the end of the string builder: "banana42"

String Builder strBuffer = new String Builder().append(4).append("U").append("Only");
String str = 4 + "U" + "Only";  // uses a StringBuilder implicitly
```

- The over-loaded method `insert()` can be used to insert primitive values, `String` objects, arrays of characters and other objects at a given index in the string builder.

```
buffer.insert(6, "Rama"); // "bananaRama42"
buffer.insert(11, 'U');   // "bananaRama4U2"
buffer.setCharAt(6, 'm'); // "bananamama4U2"
```

Operations on the string builders (cont.)

- The class `StringBuilder` does not override the `equals()` method from the `Object` class.
- String builders must be converted to strings in order to compare them:

```
boolean status = buffer1.toString().equals(buffer2.tostring());
```


Generic types

- ADTs where we can replace the *reference types*, are called *generic types*.
- The first draft of a *pair* of values:

```
// Legacy class
public class PairObj {
  private Object first;
  private Object second;
  PairObj () { }
  PairObj (Object first, Object second) {
    this.first = first;
    this.second = second;
  }
  public Object getFirst() { return first; }
  public Object getSecond() { return second; }
  public void setFirst(Object firstOne) { first = firstOne; }
  public void setSecond(Object secondOne) { second = secondOne; }
}
```

- A client of the class `PairObj`:

```
class PairObjClient {
  public static void main(String[] args) {
    PairObj firstPair = new PairObj("Adam", "Eve");
    PairObj anotherPair = new PairObj("17. May", 1905);
    Object obj = firstPair.getFirst();
    if (obj instanceof String) {// Is the object of the right type?
      String str = (String) obj;// Type conversion to the subclass String.
      System.out.println(str.toLowerCase()); // Specific method in String.
    }
  }
}
```

- The client must keep track of what is put into a `PairObj`.
- Requires checking and type conversion on lookup.

Generic classes

- A generic class which can be used to create *pairs* of objects where both objects has the same type:

```
class Pair<T> {                          // (1)
  private T first;
  private T second;
  Pair() { }
  Pair(T first, T second) {
    this.first = first;
    this.second = second;
  }
  public T getFirst() { return first; }
  public T getSecond() { return second; }
  public void setFirst(T firstOne) { first = firstOne; }
  public void setSecond(T secondOne) { second = secondOne; }
  public String toString() {
    return "(" + first.toString() + "," + second.toString() + ")";   // (2)
  }
}
```

- A generic class specifies one or more *formal type parameters*, e.g. <T>.
  - In the generic class `Pair<T>` we have used T in all locations where we used the type `Object` in the definition of the class `PairObj`.
  - The type parameter is used as a reference type in the class body: as a field type, such as return type and as parameter types in methods.
  - What actual type the type parameter `T` really represents is not known in the generic class `Pair<T>`.
- Note that formal type parameters are not specified after the class name in a constructor.

Parameterized types

- A generic class is *used* by specifying the *actual type parameters* that replaces the *formal type parameters* in the class definition at compile time.
- E.g. `Pair<String>` will introduce a new reference type during compilation, that is, pairs that only allow `String` objects, where the formal type parameter `T` is replaced by the actual type parameter `String`.
- The compiler checks that parameterized types are correctly used in the source code, so that no runtime errors can occur.
- Actual type parameters are specified after the class name, just as formal type parameters are in a generic class definition.
- Primitive data types can *not* be specified as actual type parameters.
- The relationship between generic types (`Pair<T>`) and parameterized types (`Pair<String>`) is comparable to the relationship between the declaration and calling of a method.

```
public class ParameterizedTypes {

  public static void main(String[] args) {
    Pair<String> strPair = new Pair<>("Adam", "Eve");  // (1)
//  Pair<String> mixPair = new Pair<>("17. May", 1905);// (2) Error!
    Pair<Integer> intPair = new Pair<>(2005, 2010);   // (3)
//  strPair = intPair;                // (4) Compile-time error!
    Pair<String> tempPair = strPair;  // (5) OK

    strPair.setFirst("Ole");    // (6) OK. Only String accepted.
//  intPair.setSecond("Maria"); // (7) Compile-time error!
    String name = strPair.getSecond().toLowerCase();  // (8) "eve"
    System.out.println(name);
  }
}
```

- The client does not keep track of what is put into a `Pair`.
- No checking and type conversion by reference.

Generic Interfaces

- Example:

```
interface PairRelationship<T> {
  T getFirst();
  T getSecond();
  void setFirst(T firstOne);
  void setSecond(T secondOne);
}
```

- A generic interface can be implemented by a generic (or non-generic) class:

```
class Pair<T> implements PairRelationship<T> {
  // same as before
}
```

- We can declare references of parameterized interfaces.

```
PairRelationship<String> oneStrPair = new Pair<String>("Eva", "Adam");
```

  - `Pair<String>` is a subtype of `PairRelationship<String>`.

- From the Java standard library:

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

- A class that will provide a natural order for its objects, can implement the `comparable<T>` interface:

```
class Widget implements Comparable<Widget> {
  public int compareTo(Widget widget) { /* Implementation */ }
  // ...
}
```

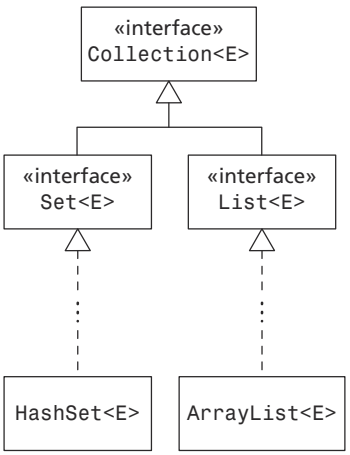
- Note that we have parameterized `Comparable<T>` with `Widget`, since it is objects of the class `Widget` that the method `compareTo()` will compare.

Generic types during compilation

- The generic class `Pair<T>` is compiled and will be represented by the class `Pair`, ie only one class file (`Pair.class`) with Java byte code is created.
- Parameterized types are used by the compiler to verify that the objects that are created are used correctly in the program.
- The runtime environment is, however, unaware of the use of generic types, ie it uses the class `Pair.`
- Since there is only one class representing all the parameterizations of a generic class, and only one instance of a static member can exist in a class.
  - Static methods cannot refer to the formal type parameters of its generic type.
- The compiler gives an *unchecked warning* in cases where the use of a generic type without any type parameters can cause problems during execution.

Collections

- A *collection* is a data structure that can maintain references to objects.
  - For example, an array of references to objects is a collection.
- Java API defines several other types of collections in the `java.util` package.
- Central to the `java.util` package are a few important *generic interfaces* that collections implement.



Interface Collection<E>

- *Basic operations* are the most frequently ones performed on collections: insertion, deletion and determine membership.

Selected basic operations from the interface Collection <E>	
`int size()`	Returns the number of items in the collection.
`boolean isEmpty()`	Find out if the collection is empty.
`boolean contains(Object element)`	Find out if element is included in the collection.
`boolean add(E element)`	*Insertion*: try to add the item to the collection and returns true if successful.
`boolean remove(Object element)`	*Deletion*: try to delete the item from the collection and returns true if successful.
`Iterator<E> iterator()`	Returns an iterator that can be used to iterate through the collection.

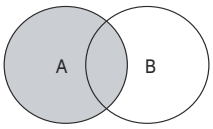
- The elements of the collection must override the `equals()` method from the `Object` class.

- *Bulk operations* are performed on the entire collection.

Selected bulk operations from the interface Collection <E>	
`boolean containsAll(Collection<?> s)`	*Subset*: returns true if all elements in the collection s are in this collection.
`boolean addAll(Collection<? extends E> s)`	*Union*: adds all items from the collection s to this collection, and returns true if this collection was modified.
`boolean retainAll(Collection<?> s)`	*Intersection*: retains in this collection only those items that are also in the collection s, and returns true if this collection was modified.
`boolean removeAll(Collection<?> s)`	*Difference*: deletes all items in this collection which are also in the collection s, and returns true if this collection was modified.
`void clear()`	Deletes all items from this collection.

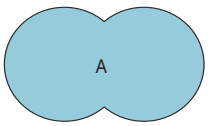
  - Note that the methods `addAll()`, `retainAll()` and `removeAll()` are destructive, that they can change the current collection.

Set Theory




```
A = [kiss, Sivle, madonna, aha, abba]
B = [TLC, wham, madonna, abba]
```

(a)



`A.addAll(B)`

After execution:

```
A = [kiss, TLC, Sivle, wham,
     aha, madonna, abba]
```

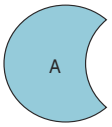
(b) Union

`A.retainAll(B)`

After execution:

```
A = [madonna, abba]
```

(c) Intersection



`A.removeAll(B)`

After execution:

```
A = [kiss, Sivle, aha]
```

(d) Difference

Traversing over a collection

- All collections implement:

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

- The `for(:)`-loop can be used to traverse a collection:

```
// Create a list of strings.
Collection<String> collection = new ArrayList<>();
collection.add("9");              // Add elements.
collection.add("1");
collection.add("1");

Iterator<String> iter = collection.iterator(); // Get an iterator.
while (iter.hasNext()) {          // More elements in the collection?
  System.out.print(iter.next());  // Print the current element.
}

for (String str : collection)
  System.out.print(str);
```


Lists

Subinterface List

- A collection that allows duplicates, and where the items are *ordered*, is called a list.
- The subinterface `List` extends the `Collection` interface to apply for lists.
- The elements have a *position* (indicated by an *index*) in list, starting with index `0`.

Selected list of operations in the interface List	
`E get(int index)`	Returns the element given by index.
`E set(int index, E element)`	Replaces the item at the given index with the element. Returns the element that was replaced.
`void add(int index, E element)`	Insert element in the specified index. The elements are shifted if necessary.
`E remove(int index)`	Deletes and returns the element in the specified index. The elements are shifted if necessary.
`int indexOf(Object obj)`	Return the index of the first occurrence of obj if the object exists, otherwise -1.

ArrayLists (ListClient.java)

- The program reads arguments from the command line into a list, and censors specific words from this list.
- We use an `import` statement at the beginning of the source file, so that we do not have to use the full package path to refer to classes from the `java.util` package.
- Words to be censored are given in a separate list (`censoredWords`).
- At (1) we create an empty list for strings:
  ```
  List<String> wordList = new ArrayList<>();
  ```
- At (2) we create an empty list (`censoredWords`) which is populated with words to be censored.
  ```
  List<String> censoredWords = new ArrayList<>();
  ```
- At (3) we use a `for(:)`-loop to traverse the word list to check every word in it.

```
for (String element : wordList) {
  if (censoredWords.indexOf(element) != -1) {
    int indexInWordList = wordList.indexOf(element);
    wordList.set(indexInWordList, CENSORED);
  }
}
```


Sets: HashSet<E>

Subinterface Set<E>

- The interface `Set` models the mathematical concept of sets that allows operations such as *union*, *intersection* and *difference* from the set theory.
- A set does *not* allow duplicate values.
- The `Set` interface does not introduce any new methods beyond those that already exist in the `Collection` interface, but specializes them for sets.

Example: Sets (SetClient.java)

- Example: Two sets with artist names.
- An empty set for concert A is created by instantiating class `HashSet`:

```
Set<String> concertA = new HashSet<>();
```

- We add the different artists using the `add()` method:

```
concertA.add("aha"); concertA.add("madonna");
```

  – If the `add()` method resulted in an element being added to the set, the method returns the value `true`.
  – Truth value `false` indicates that the element already exists in the set.

- The code below shows how we can make a copy of a set by calling the appropriate constructor in class `HashSet<E>`:

```
Set<String> allArtists = new HashSet<>(concertA);
```


Example: Create a list without duplicates (Duplicates.java)

- The code below will create a set (`wordSet`) of `String` objects from a list (`wordList`) of `String` objects, and thus remove the duplicates:

```
import java.util.*;

public class Duplicates {
  public static void main(String args[]) {
    ArrayList<String> wordList = new ArrayList<>(); // Original list
    wordList.add("two"); wordList.add("zero");
    wordList.add("zero"); wordList.add("five");
    System.out.println("Original word list: " + wordList);

    Set<String> wordSet = new HashSet<>(wordList);// New set
    wordList = new ArrayList<>(wordSet); // List without duplicates.
    System.out.println("Original list, without duplicates: " + wordList);
  }
}

Output from the program:
Original word list: [two, zero, zero, five]
Original list, without duplicates: [two, five, zero]
```

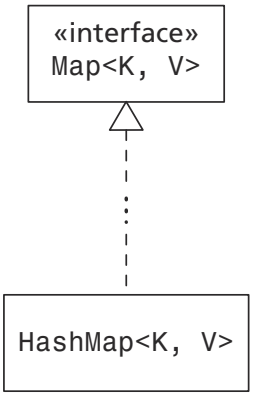
Hash tables (Maps)

- A hash table is used to store *entries*.
- An *entry* is a pair of objects, where one object (called the *key*) is associated with the second object (called the *value*).
- Example: A telephone list is a hash table, where each entry associates a telephone number (*key*) with a name (*value*).
- It is a many-to-one relationship between keys and values in a hash table:
  - Different keys may have the same value but different values may not have the same key, ie, keys are unique in a hash table.

The interface `Map<K,V>`

- The functionality of the hash tables is specified in the `Map` interface in the `java.util` package.
- The `HashMap<K,V>` class is a concrete implementation of the `Map` interface.
- We can create an empty hash table for entries <String, Integer> as shown below:

```
Map<String, Integer> wordFrequency = new HashMap<>();
```



Basic Operations in the interface `Map<K,V>`

Selected basic operations from the interface `Map<K,V>`	
`int size()`	Returns the number of entries in the hash table.
`boolean isEmpty()`	Returns true if the hash table has no entries.
`V put(K key, V value)`	Binds key to value and stores the entry. If the key had a previous entry, returns the value from the previous entry.
`V get(Object key)`	Returns the value of the entry that is key, if the key was registered before. Otherwise, returns the reference value `null`.
`V remove(Object key)`	Tries to delete the entry of the key and returns the value of this entry if the key was registered before.
`boolean containsKey(Object key)`	Returns true if the key has an entry.
`boolean containsValue(Object value)`	Returns true if the value is included in at least one entry.

Hashing

- Storage and lookup of entries in a hash table requires that it is possible to identify a key in an entry using an integer, called the *hash code*.
- Java uses the method `hashCode()` to calculate a hash code for an object, as defined in the class `Object`.
- The hash code must meet the following conditions:
  - The hash code will always be the same for an object, as long as the state of the object is not modified.
  - Two objects that are identical according to the `equals()` method must also have the same hash code.
- Class `String` and wrapper classes override both `hashCode()` and `equals()` methods from the `Object` class.

Main rule: If a class overrides `equals()`*, it should also override* `hashCode()`.

Overriding the hashCode() method

- The class `Point3D_V1` overrides neither the `equals()` method or the `hashCode()`-method:

```
class Point3D_V1 {                                                  // (1)
  int x;
  int y;
  int z;

  Point3D_V1(int x, int y, int z) {
    this.x = x;
    this.y = y;
    this.z = z;
  }

  public String toString() { return "[" + x + "," + y + "," + z + "]"; }
}
```


- The class `Point3D` overrides the `equals()` method and the `hashCode()`-method:

```
class Point3D {                                                     // (2)
  private int x;
  private int y;
  private int z;
  // ...
  /** Two points are equal if they have the same x, y and z coordinates. */
  public boolean equals(Object obj) {                               // (3)
    if (this == obj) return true;
    if (!(obj instanceof Point3D)) return false;
    Point3D p2 = (Point3D) obj;
    return this.x == p2.x && this.y == p2.y && this.z == p2.z;
  }
  /** The hash value is computed based on the coordinate values. */
  public int hashCode() {                                           // (4)
    int hashValue = 11;
    hashValue = 31 * hashValue + x;
    hashValue = 31 * hashValue + y;
    hashValue = 31 * hashValue + z;
    return hashValue;
  }
}
```

- The class `Hashing` shows what happens when we use point objects:

```
When equals() and hashCode() methods are not overridden:
Point3D_V1 p1[1,2,3]: 1671711
Point3D_V1 p2[1,2,3]: 11394033
p1.hashCode() == p2.hashCode(): false
p1.equals(p2): false
Hash table with Point3D_V1: {[1,2,3]=2, [1,2,3]=5}  <=== Keys are not unique.
Value for [1,2,3]: null                             <=== Cannot find the key.

When equals() and hashCode() methods are overridden:
Point3D pp1[1,2,3]: 328727
Point3D pp1[1,2,3]: 328727
pp1.hashCode() == pp2.hashCode(): true
pp1.equals(pp2): true
Hash table with Point3D: {[1,2,3]=5}              <=== Keys are unique.
Value for [1,2,3]: 5                              <=== Can find the key.
```


Example (MapClient.java): Basic operations in the interface `Map<K,V>`

Word (*key*)	Frequency (*value*)
to	2
be	4
or	1
...	...

- The method `put()` creates an entry and stores it in the hash table:

```
wordMap.put("to", 2); // <"to", new Integer(3)>
```

  – This method will *overwrite* any previous entry with the same key and will return the value from the previous entry.

- Lookup the value of a key:

```
int frequency = wordMap.get("to");   // 2
```

- Entry of a key can be deleted with the `remove()` method that returns the value of the entry.
- Determine whether a value occurs in one or more entries:

```
boolean keyFound = wordMap.containsKey("to");        // true
boolean valueFound  = wordMap.containsValue(2001);   // false
```

- Standard text representation of a hash table:

```
{to=2, be=4, or=1, ...}
```


Map views

- A *map view* is a collection that is associated with an underlying hash table.
- By means of such a view we can, for example, traverse the underlying hash table.
- The changes can be made through a view, and are reflected in the underlying hash table.

Selected view operations from the interface `Map`	
`public Set<K> keySet()`	(*Key View*) Returns the `Set`-view of all the keys in the hash table.
`public Collection<V> values()`	(*Value View*) Returns the `Collection`-view of all the values of all the entries in the hash table.

- *Key view*:

```
Set<String> setOfAllWords = wordMap.keySet();   // [be, or, to, ...]
```

  - Since the keys are unique, it is appropriate to create a set which does not allow duplicates.
  - The `for(:)`-loop can be used to iterate over the keys in this set in the usual way.
  - The method `get()` can be used on the hash table to retrieve the corresponding value of the key.
- *Value view*:

```
Collection<Integer> freqCollection = wordMap.values();   // [1,2,4,...]
```

  - Since values are not unique, it is appropriate to create a collection that allows duplicates.
  - The `for(:)`-loop can be used to iterate over the values in this collection in the usual way.

Using Maps (MapClient.java)

- (2) Read words from the command line:

  Repeat while arguments in command line:
    Lookup in the hash table with the current argument.
    If the current argument is not registered:
      Let the frequency of the current argument be 0, i.e. first time;
    Increase the frequency of the current argument and insert the entry.

```
for (int i = 0; i < args.length; i++) {
  // Look up if the word is already registered.
  Integer numOfTimes = wordMap.get(args[i]);
  if (numOfTimes == null) {
    numOfTimes = 0;    // Not registered before, initialize to 0.
  }
  wordMap.put(args[i], ++numOfTimes);
}
```

- (4) Determine total number of words read.
  - Total number of words read is the sum of the frequencies.
  - We create a *value view,* which is used to iterate over this collection to sum all the frequencies.

```
Collection<Integer> freqCollection = wordMap.values();
int totalNumOfWords = 0;
for (int frequency : freqCollection) {
  totalNumOfWords += frequency;
}
```

- (5) Determine all distinct words:
  - All distinct words are the keys that are registered.
  - Create a *key view* that is a set of all words (i.e., keys) from the hash table.

```
Set<String> setOfAllWords = wordMap.keySet();
```


- (6) Determine all duplicated words.:

Create an empty set for duplicate words.
Create a key view that is a set of all keys.
Repeat while there are elements in the set of all keys:
    Lookup in the hash table with the current key.
    If the frequency is not equal to 1, i.e. a duplicated word:
        Insert the word in the set of duplicate words.

```
Collection<String> setOfDuplicatedWords = new HashSet<>();
for (String key : setOfAllWords) {
  int numOfTimes = wordMap.get(key);
  if (numOfTimes != 1) {
    setOfDuplicatedWords.add(key);
  }
}
```

Subtyping with wildcard (?)

```
static double sumPair(Pair<Number> pair) {
  return pair.getFirst().doubleValue() + pair.getSecond().doubleValue();
}
...
double sum = sumPair(new Pair<Integer>(100, 200));  // (1) Error!
```

- `Pair<Integer>` is *not* a *subtype* of `Pair<Number>`, whereas the array type `Integer[]` *is* a *subtype* of array type `Number[]`.
- The parametrized type `Pair<? extends T>`:

```
static double sumPair(Pair<? extends Number> pair) {
  return pair.getFirst().doubleValue() + pair.getSecond().doubleValue();
}
```

  – The parametrized type `Pair<? extends Number>` stands for all pairs whose element type is either `Number` or *a subtype of* `Number`, in other words, `Pair<? extends Number>` is a *supertype* of `Pair<Number>`, `Pair<Double>` and `Pair<Integer>`.

```
Pair<Double> doublePair = new Pair<>(100.50, 200.50);
double newSum = sumPair(doublePair);          // (2) Ok
Pair<Number> numPair = doublePair;            // (3) Error!
Pair<? extends Number> newPair = doublePair;  // (4) Ok
```


- The parametrized type `Pair<? super Integer>`:
  – Stands for all pairs whose element type is either `Integer` or *a supertype* of `Integer`, i.e. `Pair<? super Number>` is the *supertype* of `Pair<Number>`, `Pair<Comparable>` and `Pair<Integer>`.

```
Pair<Number> numPair = new Pair<>(100.0, 200);
Pair<Integer> iPair = new Pair<>(100, 200);
Pair<? super Integer> supPair = numPair;      // (5) Ok
supPair  = iPair;                             // (6) Ok
supPair  = doublePair;                        // (7) Error!
```

- The parametrized type `Pair<?>`:
  – `Pair<?>` represents the type of *all* pairs.
  – `Pair<?>` is the supertype for all parameterized types of the generic class `Pair<T>`, i.e. `Pair<?>` is the *supertype* of `Pair<? extends Number>`, `Pair<? super Integer>`, `Pair<Number>` and `Pair<Integer>`.

```
Pair<?> pairB = numPair;                              // (8) Ok
pairB = newPair;                                      // (9) Ok
pairB = supPair;                                      // (10) Ok
pairB = new Pair<?>(100.0, 200);                      // (11) Error!
pairB = new Pair<? extends Number>(100.0, 200);       // (12) Error!
```

Generic methods

- A method can declare its own formal type parameters and use them in the method (see `GenericMethods.java`).

```
public static <T> List<T> arrayToList(T[] array) { // (1)
  List<T> list = new ArrayList<>();   // Create an empty list.
  for (T element : array) {           // Traverse the array.
    list.add(element);                // Copy current element to list.
  }
  return list;                        // Return the list.
}
```

- In a generic method, a formal type parameter `T` is only available in the method.
- It is not a requirement that a generic method must be declared in a generic class.

- We can call a generic method in the usual way.
  - The compiler determines the actual type parameter from the method call:

```
String[] strArray = {":-(", ";-)",":-)"};
List<String> strList = arrayToList(strArray);      // T is String.
System.out.println(strList);                        // [:-(, ;-), :-)]

Integer[] intArray = {2007, 7, 2};
List<Integer> intList = arrayToList(intArray);     // T is Integer.
System.out.println(intList);                        // [2007, 7, 2]
```

More Examples of Generic Methods

- The method `insertionSort()` sorts a list according to the specified `Comparator` object (see the file `GenericUtilForLists.java`):

```
static <E> void insertionSort(List<E> list, Comparator<E> comp) { ... }
```

- The method `binarySearch()` finds the index of a key in an array, if the key exists in the array (see file `GenericUtilForArrays.java`):

```
static <T extends Comparable<T>> int binarySearch(T[] array, T key) { ... }
```


Selected generic sorting and search methods in Java API

java.util.Collections
`static <T> int binarySearch(List<? extends Comparable <? super T>> list, T key)`
`static <T> int binarySearch(List<? extends T> list, T key, Comparator<? super T> comp)`
`static <T> void sort(List<T> list)`
`static <T> void sort(List<T> list, Comparator<? super T> comp)`

java.util.Arrays
`static <T> int binarySearch(T[] array, T key, Comparator<? super T> comp)`
`static <T> void sort(T[] array, Comparator<? super T> comp)`
`static <T> List<T> asList(T... argumenter)`