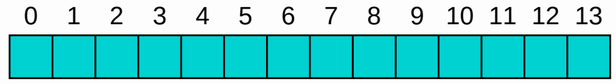
Data Structures

The basic data structures are:

- array
- list
- hashtable
- tree

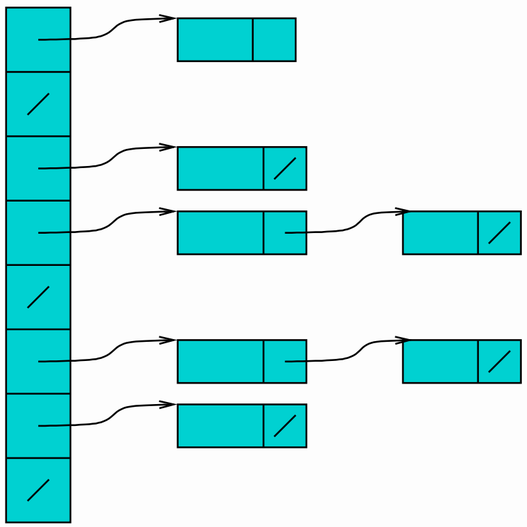
Array: indexed access, can be resizable



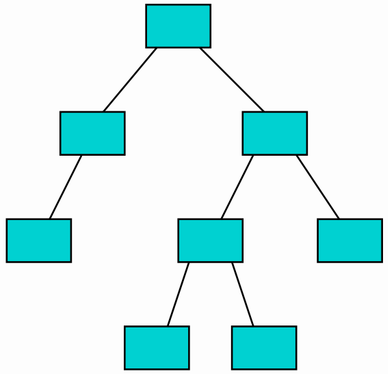
List: singly or doubly linked, can be circular

Data Structures (cont.)

Hashtable:



Tree:



Abstract Data Types

Data structures support different operations:

- insert an element
- remove an element
- search an element
- ...

Abstract data types are interfaces specifying what operations are provided. Examples of ADTs:

- **Set**
- **Dictionary** – also called **Map**
- **Vector** – resizable array
- **Stack** – also called **LIFO**
- **Queue** – also called **FIFO**
- **Priority Queue**

Collections in Java

A **collection** (sometimes called **container**) is an objects that groups multiple elements into single unit.

Earlier versions of Java included the following collections:

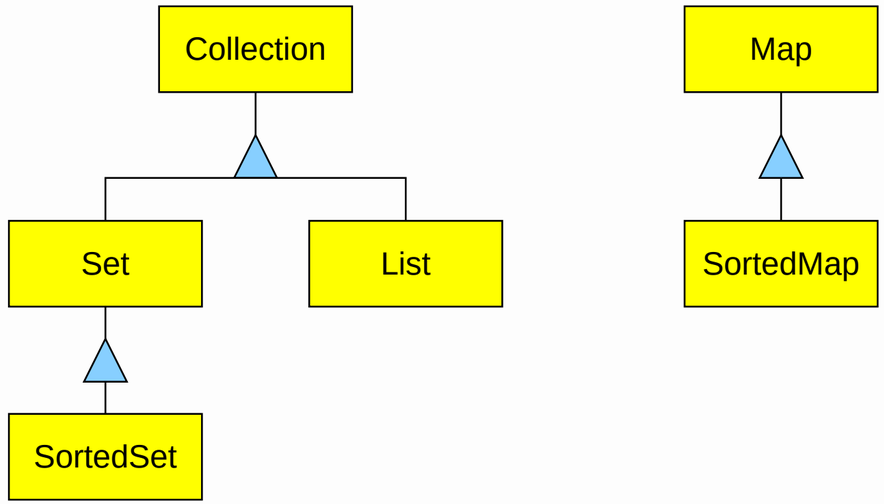
- java.util.Vector
- java.util.Hashtable
- array

Current versions of Java contain **collection framework** – a unified architecture for representing and manipulating collections. It consists of:

- **Interfaces** – abstract data types representing collections
- **Implementations** – concrete implementations of the interfaces
- **Algorithms** – methods that perform useful computations (searching and sorting)

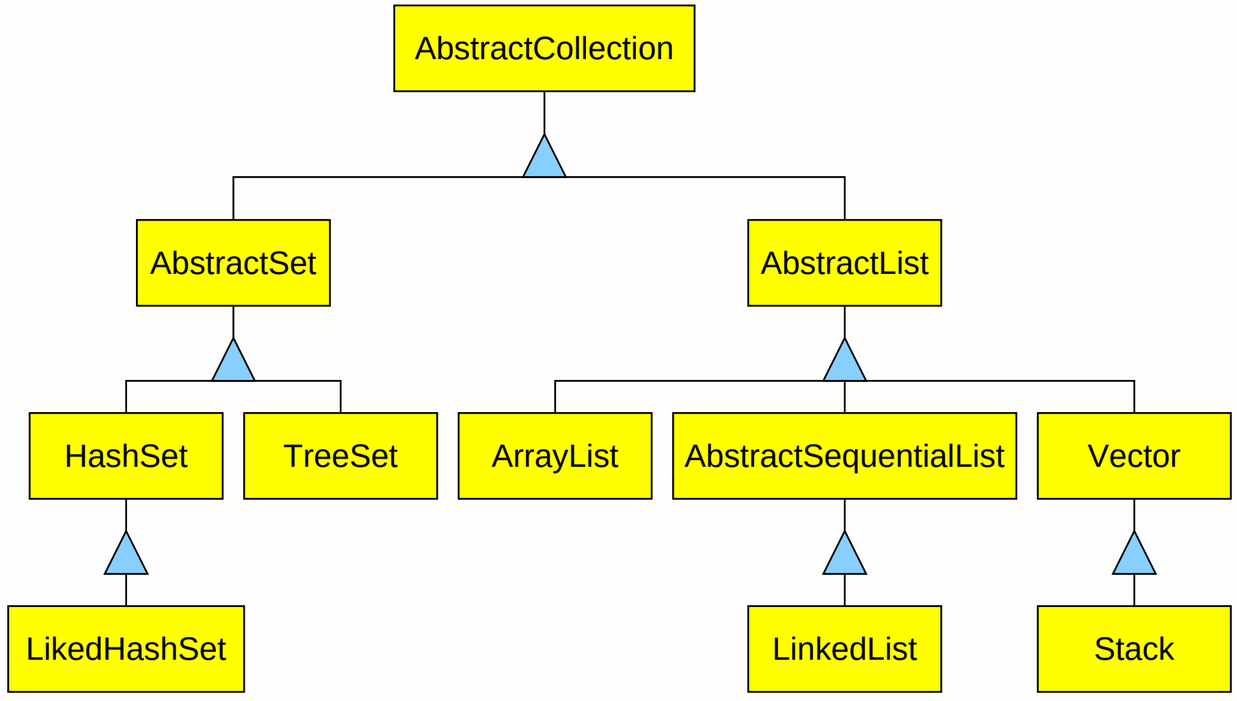
Interfaces

The collection interfaces in the package **java.util** form a hierarchy:



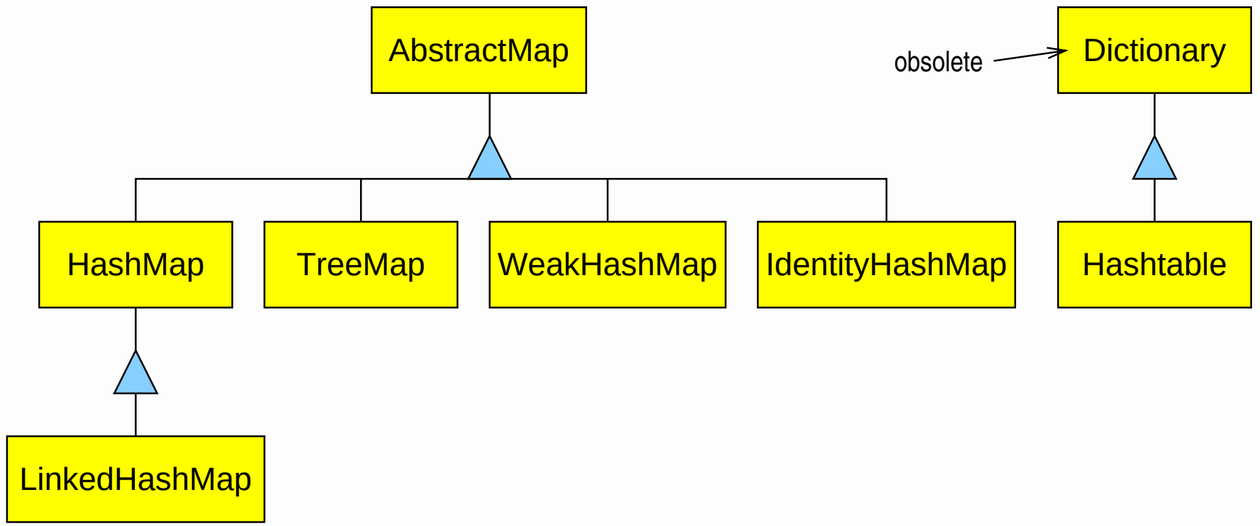
Implementations

The classes implementing collections in the package **java.util**:



Implementations (cont.)

The classes implementing maps:



The `Collection` Interface

The **Collection** is the root of the collection hierarchy.

A **Collection** represents a group of objects – its **elements**. (Some implementations allow duplicate elements and others do not.)

The primary use of the **Collection** interface is pass around collections of objects where maximum generality is desired.

The **Collection** interface declares the following basic operations:

- `int size()`
- `boolean isEmpty()`
- `boolean contains(Object o)`
- `boolean add(Object o)` - *optional*
- `boolean remove(Object o)` - *optional*
- `Iterator iterator()`

Note: Some operation are designated as **optional**. Implementations that do not implement them throw an **UnsupportedOperationException**.

Iterators

An **iterator** provides a way to access the elements of an aggregate object sequentially without exposing its underlying representation.

The **java.util.Iterator** provides uniform interface for traversing different aggregate structures.

```
public interface Iterator {
   boolean hasNext();
   Object next();
   void remove();    // optional
}
```

Example of use:

```
Collection c = new ArrayList();
   . . .    // fill the collection
for (Iterator i = c.iterator(); i.hasNext(); ) {
    Object o = i.next();
       . . .  // process the element
}
```

Enumerations

Earlier implementations of Java used the **java.util.Enumeration** interface instead of **iterator**:

```
public interface Enumeration {
    boolean hasMoreElements();
    Object nextElement();
}
```

The differences between them are:

- **Iterator** allows the caller to remove elements from the underlying collection.
- Method names have been improved in **Iterator**.

New implementations should use **Iterator** in preference to **Enumeration**.

Iterators (cont.)

The **Iterator** interface contains the optional method remove() that removes from the underlying collection the last element that was returned by next():

- The remove() method may be called only once per call to next() - an exception is thrown if this condition is violated.
- The remove() method is the **only** safe way to modify a collection during iteration.
- The behavior is unspecified if the underlying collection is modified in any other way while iteration is in progress.

Bulk Operations

The **bulk operations** perform some operation on an entire **Collection** in a single shot:

- boolean containsAll(Collection c)
- boolean addAll(Collection c) - *optional*
- boolean removeAll(Collection c) - *optional*
- boolean retainAll(Collection c) - *optional*
- void clear() - *optional*

For example, to remove **all** instances of a specified element e from a collection c we can use:

```
c.removeAll(Collections.singleton(e));
```

Note: The class **Collections** contains many useful static methods that operate on collections. The singleton() method returns an immutable collection (set) containing only the specified object.

Array Operations

The `toArray()` allow the contents of a **Collection** to be translated into an array:

- `Object[] toArray()`
- `Object[] toArray(Object[] a)`

The following code dumps the contents of `c` into a newly allocated array:

```
Object[] a = c.toArray();
```

Suppose `c` is a collection known to contain only strings. The following code can be used to dump the contents of `c` into a newly allocated array of `String`:

```
String[] a = (String[])c.toArray(new String[0]);
```

> **Note:** If the collection fits in the specified array, this array is used, otherwise a new array is allocated.

The Set Interface

A **Set** is a **Collection** that cannot contain duplicate elements. It models a mathematical **set** abstraction.

The **Set** interface contains **no** methods than those inherited from **Collection**.

There are two general-purpose **Set** implementations:

- **HashSet** – stores its elements in a hashtable, it is the best-performing implementation.
- **TreeSet** – stores its elements in a red-black tree, guarantees the order of iteration (the elements will be sorted).

The following code creates a new collection containing the same elements as the collection c, but with all duplicates eliminated:

```
Collection d = new HashSet(c);
```

The `Set` Interface (cont.)

Example of use of a **Set** that prints out any duplicate words, the number of distinct words, and a list of the words with duplicates eliminated:

```
import java.util.*;

public class FindDuplicates {
    public static void main(String[] args) {
        Set s = new HashSet();
        for (int i = 0; i < args.length; i++) {
            if (!s.add(args[i])) {
                System.out.println("Duplicate detected: "
                                   + args[i]);
            }
        }
        System.out.println(s.size() +
                           " distinct words detected: " + s);
    }
}
```

The `Set` Interface (cont.)

The bulk operations on sets correspond to standard set-algebraic operations:

- `s1.containsAll(s2)` – returns **`true`** if `s2` is a **subset** of `s1`

$$s_2 \subseteq s_1$$

- `s1.addAll(s2)` – transforms `s1` into the **union** of `s1` and `s2`

$$s_1 \cup s_2$$

- `s1.retainAll(s2)` – transforms `s1` into the **intersection** of `s1` and `s2`

$$s_1 \cap s_2$$

- `s1.removeAll(s2)` – transforms `s1` into the **set difference** of `s1` and `s2`

$$s_1 - s_2$$

The `List` Interface

A **List** is an ordered **Collection** (sometimes called a **sequence**). Lists may contain duplicate elements.

There are two general-purpose **List** implementations:

- **ArrayList** – generally the best-performing implementation
- **LinkedList** – offers better performance under certain circumstances

The **List** contains methods for positional access that manipulate elements based on their numerical position in the list:

- `Object get(int index)`
- `Object set(int index, Object element)` - *optional*
- `void add(int index, Object element)` - *optional*
- `Object remove(int index)` - *optional*
- `boolean addAll(int index, Collection c)` - *optional*

The `List` Interface (cont.)

For example, the following method swaps two elements of a list:

```
private static void swap(List a, int i, int j) {
    Object tmp = a.get(i);
    a.set(i, a.get(j));
    a.set(j, tmp);
}
```

The following method randomly permutes the specified **List** using the specified source of randomness:

```
public static void shuffle(List a, Random rnd) {
    for (int i = a.size(); i > 1; i--) {
        swap(a, i-1, rnd.nextInt(i));
    }
}
```

Note: The class **Collections** contains such method `shuffle()`.

The `List` Interface (cont.)

- The `remove()` operation always removes the **first** occurrence of the specified element.
- The `add()` and `addAll()` operations always append the new element(s) to the **end** of the list.
- To concatenate one list to another we can use:

```
list1.addAll(list2);
```

- The non-destructive version of concatenation:

```
List list3 = new ArrayList(list1);
list3.addAll(list2);
```

- The **List** interface contains two methods for searching:
  - `int indexOf(Object o)`
  - `int lastIndexOf(Object o)`

The `ListIterator` Interface

The **List** interface supports its own extended version of iterator:

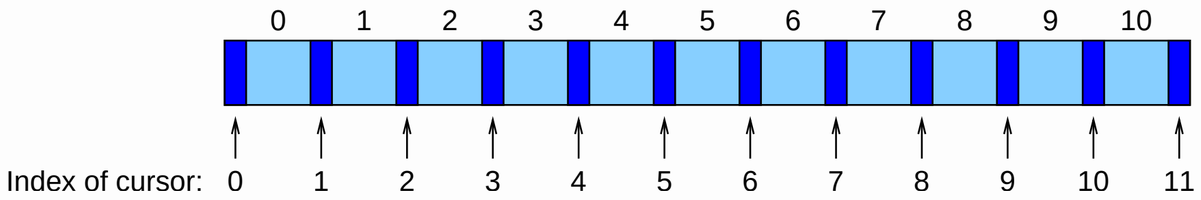
```
public interface ListIterator extends Iterator {
    boolean hasNext();
    Object next();

    boolean hasPrevious();
    Object previous();

    int nextIndex();
    int previousIndex();

    void remove();         // optional
    void set(Object o);    // optional
    void add(Object o);    // optional
}
```

The `ListIterator` Interface (cont.)

To obtain `ListIterator` we can use **`List`** methods:

- `ListIterator listIterator()`
- `ListIterator listIterator(int index)`

A list iterators has a cursor pointing **between** elements:



The `ListIterator` Interface (cont.)

Iterating backwards in a list:

```
for (ListIterator i = list.listIterator(list.size());
        i.hasPrevious(); ) {
    Object o = i.previous();
     . . .
}
```

A method that replaces all occurrences of one specified value with another:

```
public static void replace(List l, Object x, Object y) {
    for (ListIterator i = l.listIterator(); i.hasNext(); ) {
        if (x == null ? i.next() == null
                      : x.equals(i.next())) {
            i.set(y);
        }
    }
}
```

The `List` Interface (cont.)

The **List** interface contains a method returning a **range-view**:

- `List subList(int fromIndex, int toIndex)`

The returned **List** contains the portion of the original list whose indexes range from `fromIndex`, inclusive, to `toIndex`, exclusive.

Changes in the former **List** are reflected in the latter.

For example, to remove a range of elements from a list we can use:

```
list.subList(fromIndex, toIndex).clear();
```

Searching for an element in a range:

```
int i = list.subList(fromIndex, toIndex).indexOf(o);
int j = list.subList(fromIndex, toIndex).lastIndexOf(o);
```

The `Collections` Class

The **Collections** class contains static methods implementing different algorithms working on collections. Most of them apply specifically to **List**:

- `void sort(List list)`
- `int binarySearch(List list, Object key)`
- `void reverse(List list)`
- `void shuffle(List list)`
- `void fill(List list, Object obj)`
- `void copy(List dest, List src)`

There is a similar class called **Arrays** containing as static methods algorithms working on arrays.

The Map Interface

A **Map** is an object that maps keys to values.

A map cannot contain duplicate keys: Each key can map to at most one value.

The most important methods:

- Object put(Object key, Object value) - *optional*
- Object get(Object key)
- Object remove(Object key) - *optional*
- boolean containsKey(Object key)
- boolean containsValue(Object value)
- int size()
- boolean isEmpty()

The `Map` Interface (cont.)

Other methods:

- `void putAll(Map t)` - *optional*
- `void clear()` - *optional*
- `Set keySet()`
- `Collection values()`
- `Set entrySet()`

The **Collection**-view methods provide the **only** means to iterate over a **Map**:

```
for (Iterator i = m.keySet().iterator(); i.hasNext(); ) {
    System.out.println(i.next());
}
```

The `Map` Interface (cont.)

There are two general-purpose **Map** implementations:

- **HashMap** – stores its entries in a hash table, it is the best-performing implementation
- **TreeMap** – stores its entries in a red-black tree, guarantees the order of iteration

There is also an older class **Hashtable**.

Hashtable has been retrofitted to implement **Map**.

Object Ordering

Objects that implement the **java.lang.Comparable** interface can be ordered automatically. The **Comparable** interface provides **natural ordering** for a class:

```
public interface Comparable {
    public int compareTo(Object o);
}
```

The method o1.compareTo(o2) returns:

- a negative integer – if o1 is less than o2
- zero – if o1 is equal to o2
- a positive integer – if o1 is greater than o2

Many standard classes such as **String** and **Date** implement the **Comparable** interface.

Object Ordering (cont.)

```
import java.util.*;

public class Name implements Comparable {
    private String firstName, lastName;

      . . .

    public boolean equals(Object o) {
        if (!(o instanceof Name)) return false;
        Name n = (Name)o;
        return firstName.equals(n.firstName) &&
               lastName.equals(n.lastName);
    }

    public int hashCode() {
        return 31 * firstName.hashCode() +
               lastName.hashCode();
    }

  . . .
```

Object Ordering (cont.)

```
        . . .

    public int compareTo(Object o) {
        Name n = (Name)o;
        int cmp = lastName.compareTo(n.lastName);
        if (cmp != 0) return cmp;
        return firstName.compareTo(n.firstName);
    }
}
```

Note how methods equals() and hashCode() are redefined to be consistent with compareTo().

Comparators

If we want to sort objects in some other order than natural ordering, we can use the **Comparator** interface:

```
public interface Comparator {
    int compare(Object o1, Object o2);
}
```

A **Comparator** is an object that encapsulates ordering.

The compare() method compares two its arguments, returning a negative integer, zero, or a positive integer as the first argument is less than, equal to, or greater than the second.

Methods implementing different algorithms in classes **Collections** and **Arrays** allow to specify the comparator that should be used in these algorithms.

The `SortedSet` Interface

A **SortedSet** is a **Set** that maintains its elements in ascending order, sorted according to the elements' **natural order**, or according to a **Comparator** provided at **SortedSet** creation time.

The **SortedSet** adds the following methods to the methods declared in the **Set** interface:

- SortedSet subSet(Object fromElement, Object toElement)
- SortedSet headSet(Object toElement)
- SortedSet tailSet(Object fromElement)
- Object first()
- Object last()
- Comparator comparator()

The `SortedSet` Interface (cont.)

There are some differences on behavior of methods inherited from the **Set** interface:

- The iterator returned by the `iterator()` traverses the sorted set in order.
- The array returned by `toArray()` contains the sorted set's elements in order.

The **SortedSet** interface is implemented by the class:

- **TreeSet**

The `SortedMap` Interface

A **SortedMap** is a **Map** that maintains its entries in ascending order, sorted according to the keys' **natural order**, or according to a **Comparator** provided at **SortedMap** creation time.

The **SortedMap** adds the following methods to the methods declared in the **Map** interface:

- `Comparator comparator()`
- `SortedMap subMap(Object fromKey, Object toKey)`
- `SortedMap headMap(Object toKey)`
- `SortedMap tailMap(Object fromKey)`
- `Object firstKey()`
- `Object lastKey()`

There is one class implementing the **SortedMap** interface:

- **TreeMap**

Implementations

The general-purpose implementations are summarized in the table below:

	Implementations			
	Hash Table	**Resizable Array**	**Balanced Tree**	**Linked List**
Set	HashSet		TreeSet	
List		ArrayList		LinkedList
Map	HashMap		TreeMap	

The **SortedSet** and **SortedMap** interfaces are implemented by **TreeSet** and **TreeMap** classes.

The `BitSet` Class

The **java.util.BitSet** class implements a vector of bits that grows as needed.

Each component of the bit set has a boolean value. The bits of a BitSet are indexed by nonnegative integers. Individual indexed bits can be examined, set, or cleared.

One **BitSet** may be used to modify the contents of another **BitSet** through logical AND, logical inclusive OR, and logical exclusive OR operations.

The **BitSet** class can used as an efficient implementation of a set if the corresponding universe of possible values is finite and small.

The logical operations then correspond to the set operations.

Note: The **BitSet** class is not part of the collection framework.