Estruturas de Informação

JAVA Collections Framework

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Java Collections Framework (JCF)

Unified architecture for representing and manipulating collections

A collection is an object that maintains references to others objects

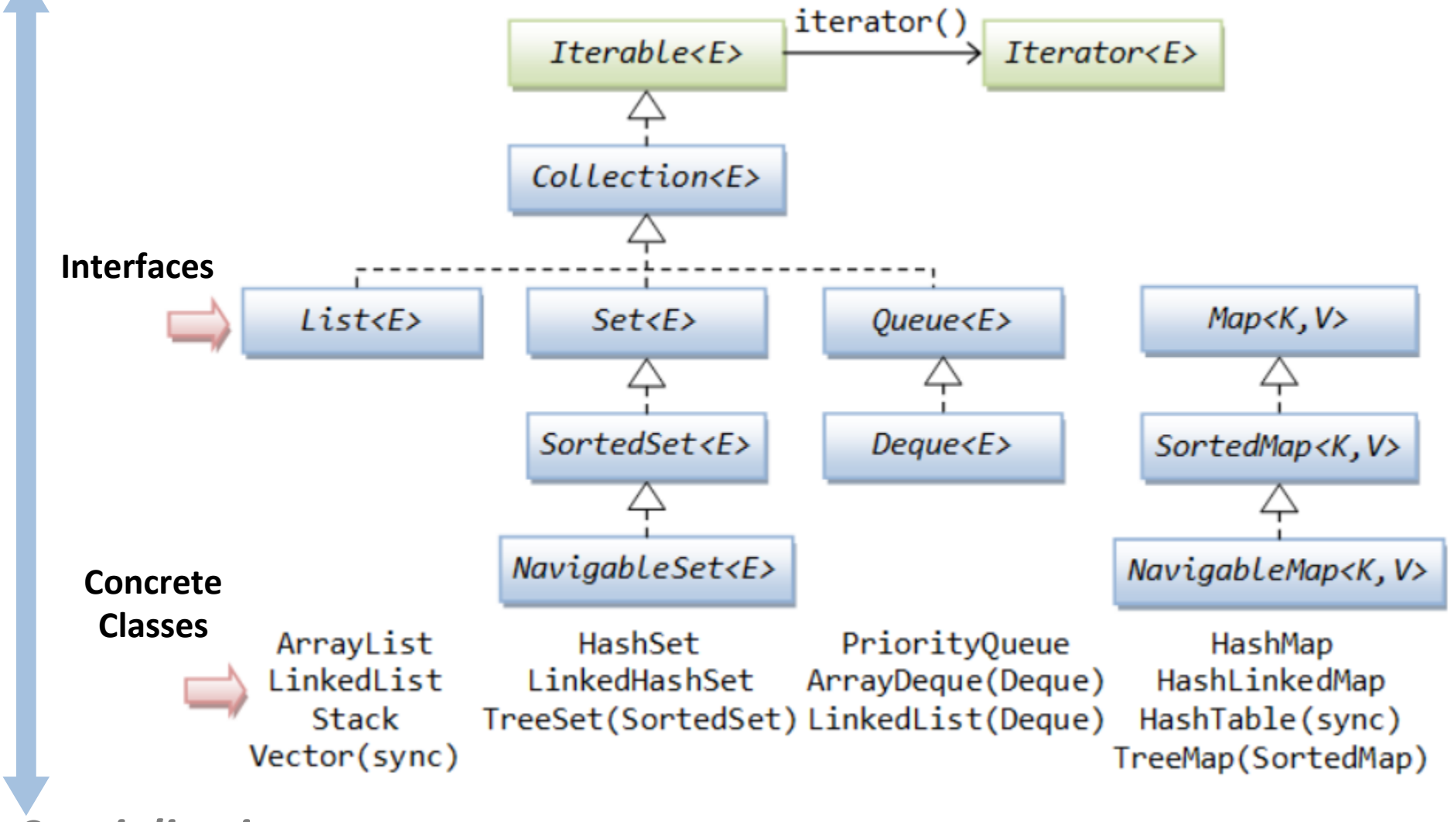
- Essentially a subset of data structures

JCF forms part of the **java.util** package and provides:

- Interfaces
  - Each defines the operations and contracts for a particular type of collection (List, Set, Queue, etc.)
  - Idea: when using a collection object, it's sufficient to know its interface
- Implementations
  - Reusable classes that implement above interfaces (e.g. LinkedList, HashSet)
- Algorithms
  - Useful polymorphic methods for manipulating and creating objects whose classes implement collection interfaces
  - Sorting, index searching, reversing, replacing etc.

Collection Interfaces

Generalisation



Specialisation

Generics

Generics

- The interfaces, classes and methods of Java Collections Framework allow *types* to be passed as *parameters*

```
List<Employee> emps = new ArrayList<>();
```

- A class that is defined with a parameter for a type is called a **generic class** or a **parameterized class**
- With the type parameter, **the *compiler* ensures** that **we use the collection with objects of a compatible type only**
- Another benefit is that we won't need to cast the objects we get from the collection:

```
Employee e = emps.get(0);
```

- Object type errors are now detected at **compile time**, rather than throwing casting exceptions at runtime

Multiple Type Parameters

- A generic class can have any number of type parameters

```
public class Pair<T,S> {

   private T first;
   private S second;

   // Constructors:
   public Pair() {
      first = null;
      second = null; }

   public Pair(T firstElem, S secondElem) {
      first = firstElem;
      second = secondElem; }
   …
   public boolean equals(Object otherObj) {

      if (otherObj == null)
        return false;
      if (getClass() != otherObj.getClass())
        return false;

      Pair<T,S> otherPair = (Pair<T,S>) otherObj;
      return (first.equals(otherPair.first) &&
              second.equals(otherPair.second)); }
   }
```

Limitations on type parameter usage

- The type plugged in for a type parameter must always be a **reference type**: it cannot be a primitive type such as int, double,….
- The type parameter **cannot be used as a constructor** name or like a constructor:

```
T object = new T();  //wrong!
Pair<String,Integer> filmrating = new Pair<>("Magnolia",8);
```

- Arrays such as the following are illegal:

```
T[] a = new T[10]; //wrong!
Pair<String,Integer>[] a = new Pair<String,Integer>[10]; //wrong!
```

- Although this is a reasonable thing to want to do, it is not allowed given the way that Java implements generic classes

```
ArrayList<Pair<String,Integer>> filmsrating = new ArrayList<>(10);
```

Bounds for Type Parameters

To ensure that only classes that implement the **Comparable** interface are plugged in for **T**, the class must be define as follows:

```
public class Example <T extends Comparable>
```

- "**extends Comparable**" serves as a *bound* on the type parameter **T**
- Any attempt to plug in a type for **T** which does not implement the **Comparable** interface will result in a **compiler error message**
- A bound on a type may be a class name (rather than an interface name)

```
public class Example <T extends Class1>
```

- A type parameter can have multiple bounds, If one of the bounds is a class, it must be specified first

```
public class Two<T1 extends Class1 & Comparable>
```

Generic Classes and Exception

- It is not permitted to create a generic class with **Exception, Error, Throwable, or any descendent class of Throwable**
- A generic class cannot be created whose objects are throwable

```
public class GEx<T> extends Exception   //wrong!
```

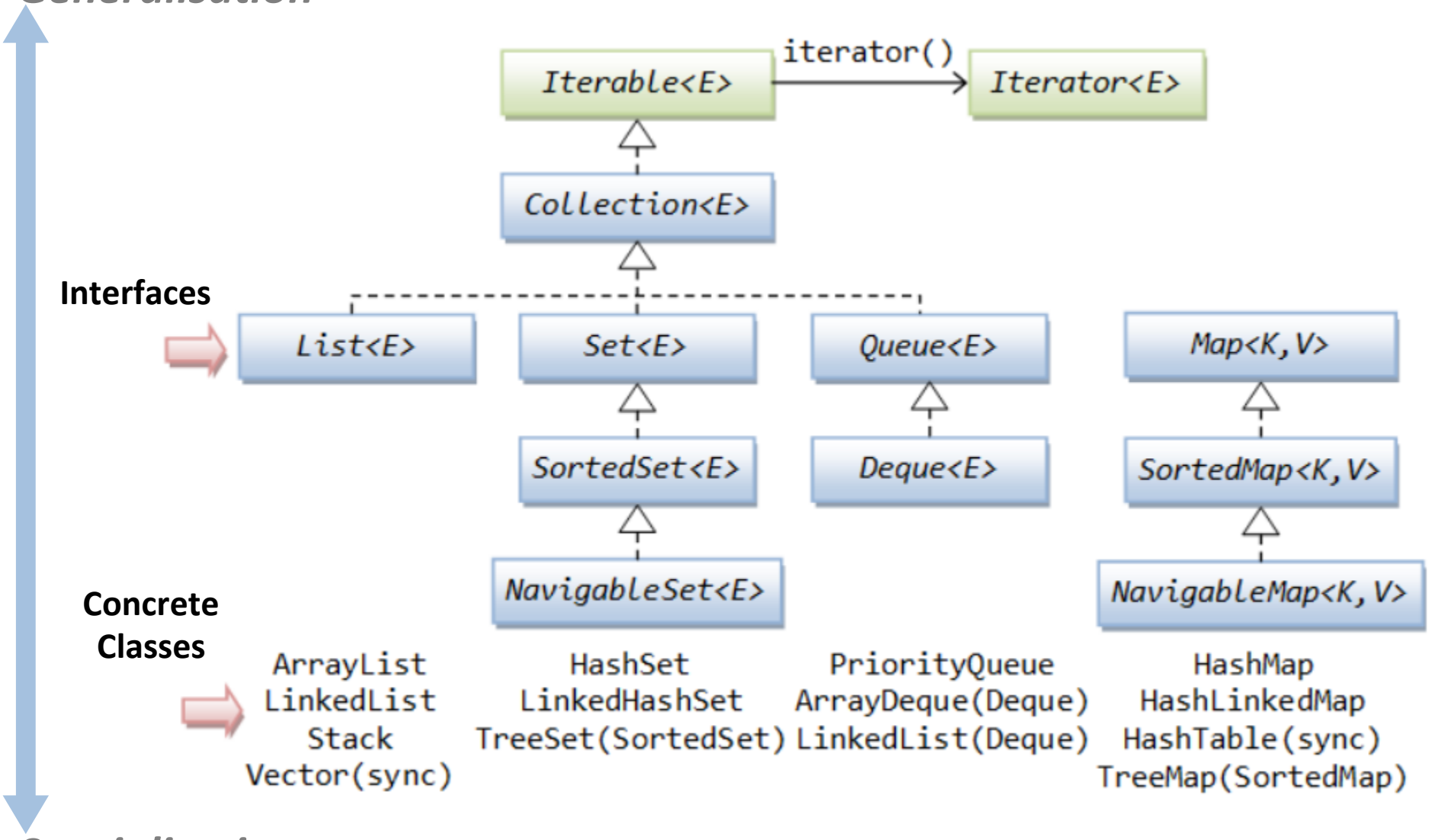
This will generate a compiler error message

Generic Methods

- When a generic class is defined, the type parameter can be used in the definitions of the methods for that generic class
- In addition, a generic method can be defined that has its own type parameter that is not the type parameter of any class
  - A generic method can be a member of an ordinary class or a member of a generic class that has some other type parameter
  - The type parameter of a generic method is local to that method, not to the class
- The type parameter must be placed (in angular brackets) after all the modifiers, and before the returned type:

```
public static<T> T genMethod(T[] a)
```

Java Collections Framework



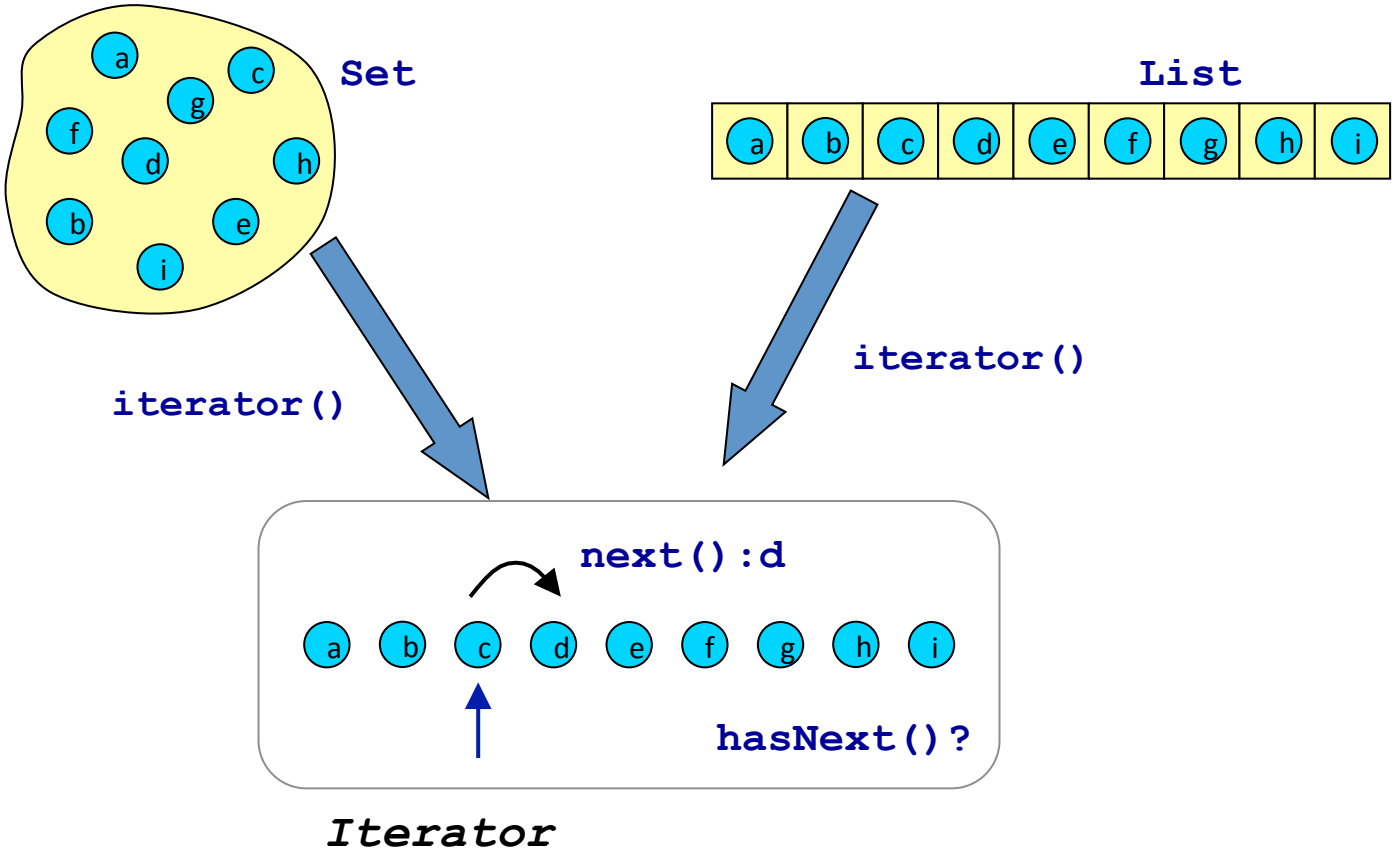
Collection Interface

- Defines fundamental methods
  - int size();
  - boolean isEmpty();
  - boolean contains(Object element);
  - boolean add(Object element); // Optional
  - boolean remove(Object element); // Optional
  - Iterator iterator();
- These methods are enough to define the basic behavior of a collection
- Provides an Iterator to step through the elements in the Collection

Iterator

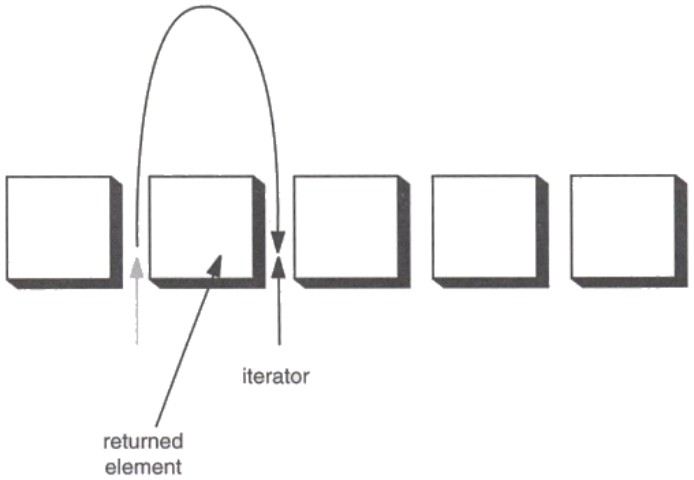
java.util.Iterator<E>

Iterators provide a generic way to traverse through a collection regardless of its implementation



Iterator Interface

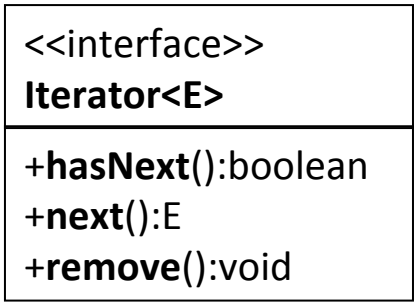
- Defines three fundamental methods
  - Object next()
  - boolean hasNext()
  - void remove()
- These three methods provide access to the contents of the collection
- An Iterator knows position within collection
- Each call to next() "reads" an element from the collection
  - Then you can use it or remove it



Using an Iterator

- Code snippet for collection iteration:

```
public void displayContents(Collection<Item> items)
{
  Iterator<Item> it = items.iterator();
  while(it.hasNext()) {
    Item item = it.next();
    System.out.println(item);
  }
}
```



- Above method takes in an object whose class implements Collection
  - List, ArrayList, LinkedList, Set, HashSet, TreeSet, Queue, MyOwnCollection, etc.
- We know any such object can return an Iterator through method iterator()
- We don't know the exact implementation of Iterator we are getting, but **we don't care**, as long as it provides the methods next() and hasNext()

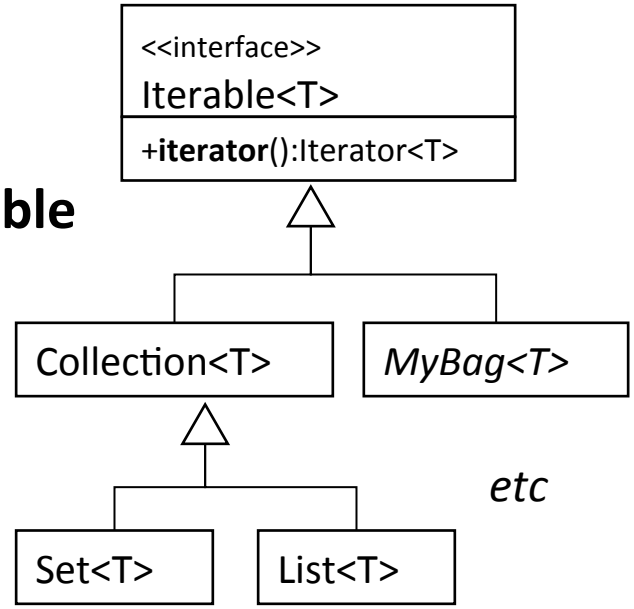
Iterable<T>

```
for (Item item : items) {
  System.out.println(item);
}
```

=

```
Iterator<Item> it = items.iterator();
while(it.hasNext()) {
  Item item = it.next();
  System.out.println(item);
}
```

- This is called a **"for-each"** statement
  - For each **item** in **items**
- This is possible as long as items is of type **Iterable**
  - Defines single method iterator()
- **Collection** (and hence all its subinterfaces) implements **Iterable**



java.util.Collections

- The Collections class offers many very useful utilities and algorithms for manipulating and creating collections
  - **Sorting** lists
  - Index searching
  - Finding min/max
  - Reversing elements of a list
  - Swapping elements of a list
  - Replacing elements in a list
  - Other nifty tricks
- Saves you having to implement them yourself → **reuse**

Sorting

Collections.sort()

What types of objects is it possible to sort?

- Anything that has an **ordering**

Two sort() methods: sort a given List according to either

1. *natural ordering* of elements or
2. an externally defined ordering

1)
```
public static <T extends Comparable<? super T>> void sort(List<T> list)
```

2)
```
public static <T> void sort(List<T> list, Comparator<? super T> c)
```

1. Only accepts a List parameterised with type implementing Comparable
2. Accepts a List parameterised with any type as long as you also give it a Comparator implementation that defines the ordering for that type

java.lang.Comparable<T>

- A **generic interface** with a single method: **int compareTo(T)**
  - Return 0 if this == other
  - Return **any positive integer** if this > other
  - Return **any negative integer** if this < other
- Implement this interface to define **natural ordering** on objects of type T

```
public class Pair <T extends Comparable<T>, S extends Comparable<S>>
                                        implements Comparable< Pair<T,S> >{
      ...
      public int compareTo(Pair<T,S> other) {
         return this.getSecond().compareTo(other.getSecond());
      }
```

java.lang.Comparable<T>

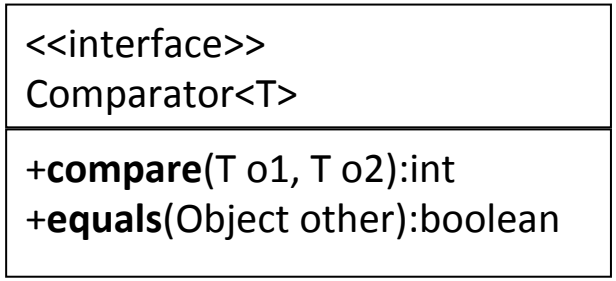
```
Pair<String,Integer> film1 = new Pair<>("Magnolia",8);
Pair<String,Integer> film2 = new Pair<>("Crocodile Dundee",3);
Pair<String,Integer> film3 = new Pair<>("Paris Texas",6);

ArrayList<Pair<String,Integer>> filmsrating = new ArrayList<>(10);

filmsrating.add(film1);
filmsrating.add(film2);
filmsrating.add(film3);
filmsrating.sort(filmsrating);
System.out.println("\nFilms sorted by rating");
for (Pair<String,Integer> p : filmsrating )
    System.out.println("Pair: (“+p.getFirst()+", rate “+
                                p.getSecond()+")");

List<CD> albums = new ArrayList<CD>();
albums.add(new CD(”A Head Full of Dreams",”Coldplay",2.80));
//etc...
Collections.sort(albums);
```

Pair: (Crocodile Dundee, rate 3)
Pair: (Paris Texas, rate 6)
Pair: (Magnolia, rate 8)

CD does not implement a Comparable interface

java.util.Comparator<T>

- Useful if the type of elements to be sorted is not Comparable, or we want to define an alternative ordering
- Also a generic interface that defines methods **compare(T,T)** and **equals(Object)**
  - Usually only need to define **compare(T,T)**




```
public static class PairComparator<T extends Comparable<T>, S
extends Comparable<S>> implements Comparator < Pair<T,S> > {

     public int compare(Pair<T,S> p1, Pair<T,S> p2) {
           return p1.getFirst().compareTo(p2.getFirst());
     }
}
```

Comparator defined using Comparable ☺

Comparator sorting

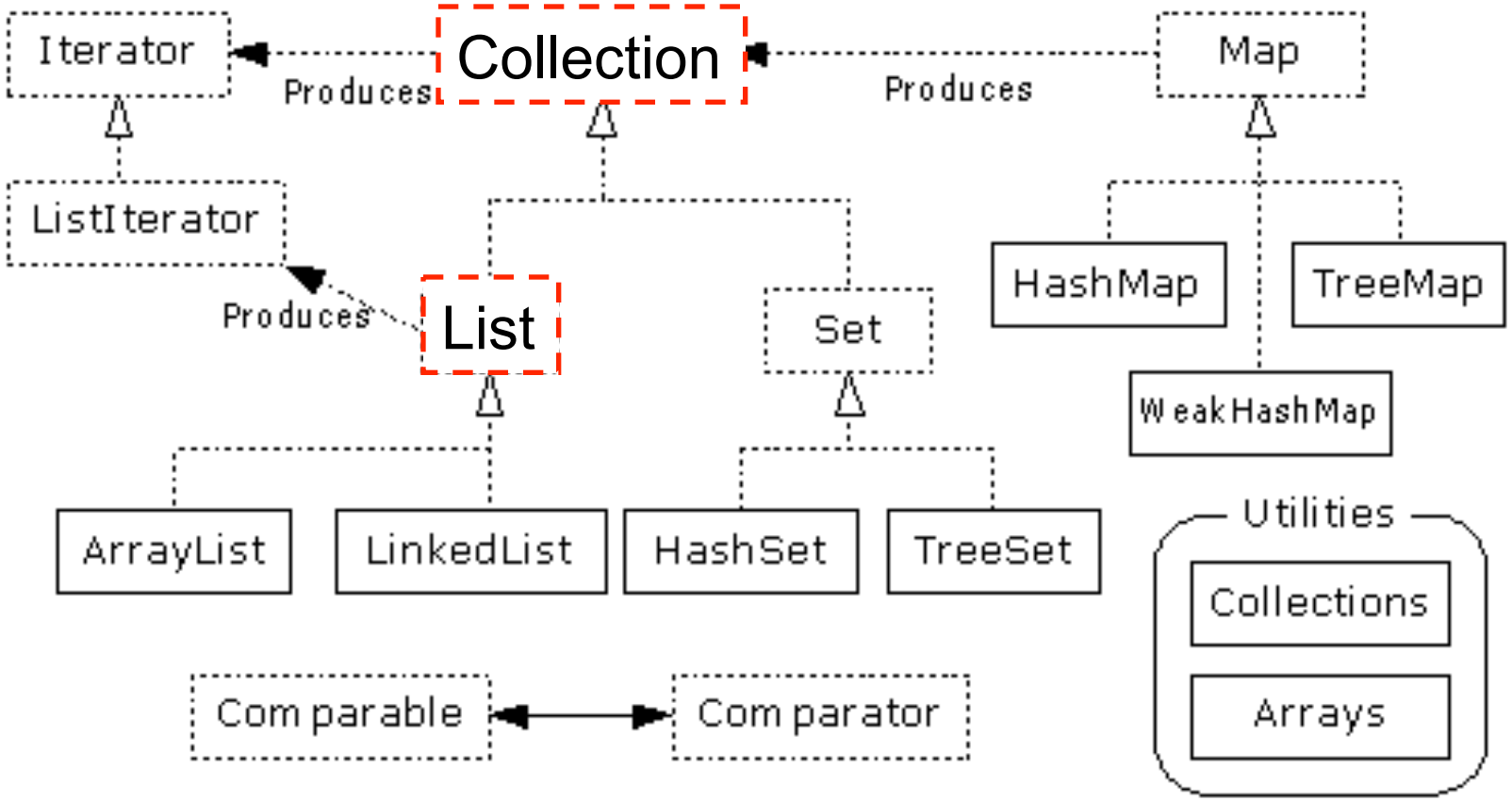
```
implements Comparator<CD>
```

```
Collections.sort(filmsrating, new PairComparator());
System.out.println("\nFilms sorted by Title");
for (Pair<String,Integer> p : filmsrating )
   System.out.println("Pair: (" + p.getFirst() + ", rate " +
                                  p.getSecond()+")");
```

```
Pair: (Crocodile Dundee, rate 3)
Pair: (Magnolia, rate 8)
Pair: (Paris Texas, rate 6)
```

- Note, in sort(), Comparator overrides natural ordering
  - i.e. even if we define natural ordering for Pair, the given comparator is still going to be used instead
  - (On the other hand, if you give **null** as Comparator, then natural ordering is used)

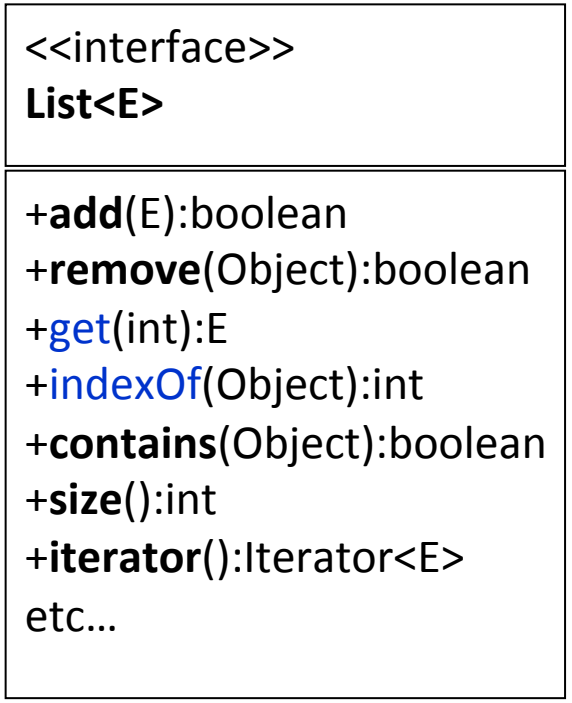
List Interface Context



List Interface

- The List interface adds the notion of *order* to a collection

- The user of a list has control over where an element is added in the collection
- With a list it is possible:
  - to store duplicate elements
  - to specify where the element is stored
  - to access the element by index



- Provides a ListIterator to step through the elements in the list

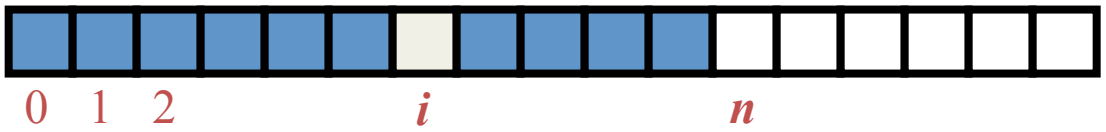
ListIterator Interface

- Extends the Iterator interface
- Defines three fundamental methods
  - void **add(Object o)** - before current position
  - boolean **hasPrevious()**
  - Object **previous()**
- The addition of these three methods defines the basic behavior of an ordered list
- A ListIterator knows position within list

List<E> implementations

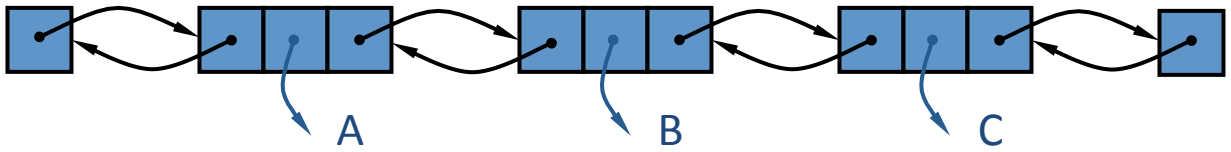
Two concrete implementations of the List ADT in the Java Collection:

- **java.util.ArrayList**



An array is fixed once it is created

- **java.util.LinkedList**



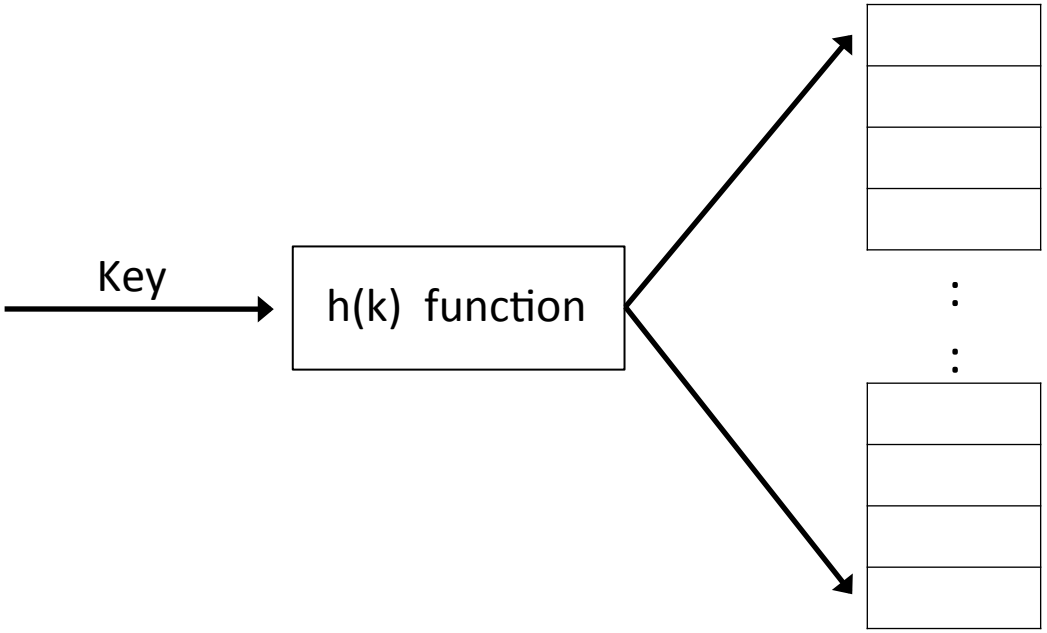
A list can grow or shrink dynamically

Hash Table

Hash Table

- Is a data structure where the location of an item is determined
  - Directly as a function of the item itself

- If the hash table is implemented as an array A of size N the **hash function h(k)** must map a key k into an integer range 0, 1,..., N-1



From Keys to Indices

- The mapping of keys to indices of a hash table is called a **hash function**
- An essential requirement of a hash function is to map equal keys to equal indices
- A "good" hash function must be:
  - easy and fast to compute
  - minimize the **probability of collisions**, by distribute the items evenly throughout the hash table
- A perfect hash function can be constructed if we know in advance all the keys to be stored in the table (almost never…)

Hash Functions: Examples

A hash function is a composition of two functions:

1. **Hash code:**
   - Key = Character: char value cast to an int -> it's ASCII value
   - Key = Date: value associated with the current time
   - Key = Double: value generated by its bitwise representation
   - Key = Integer: the int value itself
   - Key = String: a folded sum of the character values
   - Key = URL: the hash code of the host name

2. **Compression function**

   Maps the hash code to a valid Index for example, modulus operator (%) with table size

```
idx = hash(val) % size;
```

To get a good distribution of indices, **table size** should be a **prime number**

Java Hash

- Java provides a hashCode() method for the Object class, which typically returns the 32-bit memory address of the object
- This default hash code would work poorly for Integer and String objects
- The hashCode() method **should be suitably redefined by classes**

Collision

- A collision occurs when two distinct items are mapped to the same position
- Example: store six elements in a **seven** element array, where the hash function converts the 3rd letter of each name to an index

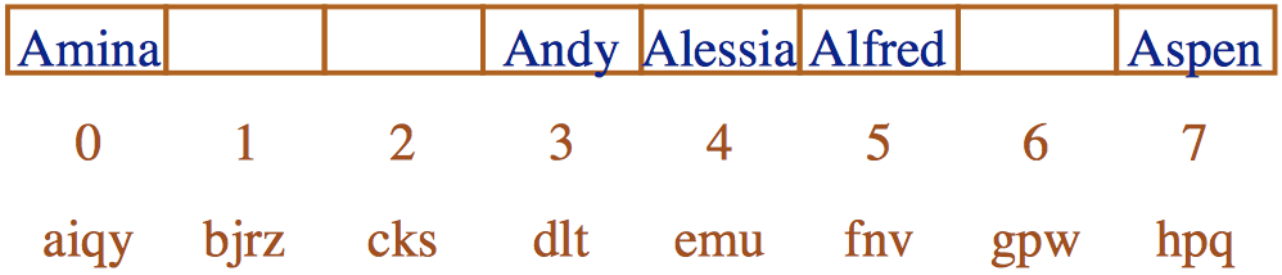
Alfred	**f = 5 % 7 = 5**
Alessia	**e = 4 % 7 = 4**
Amina	**i = 7 % 7 = 0**
Amy	**y = 24 % 7 = 3**
Andy	**d = 3 % 7 = 3**
Anne	**n = 12 % 7 = 5**

Collisions Resolution

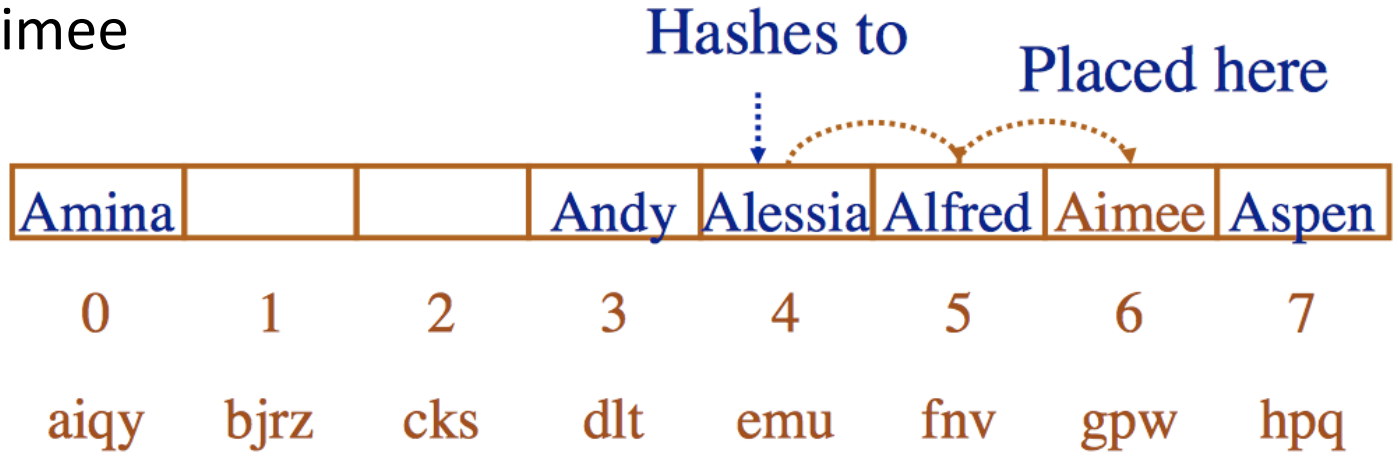
There are two general approaches to resolving collisions:

1. **Open address hashing**:

   If that position is filled, next position is examined, then next, and so on until an empty position is filled



To add: Aimee

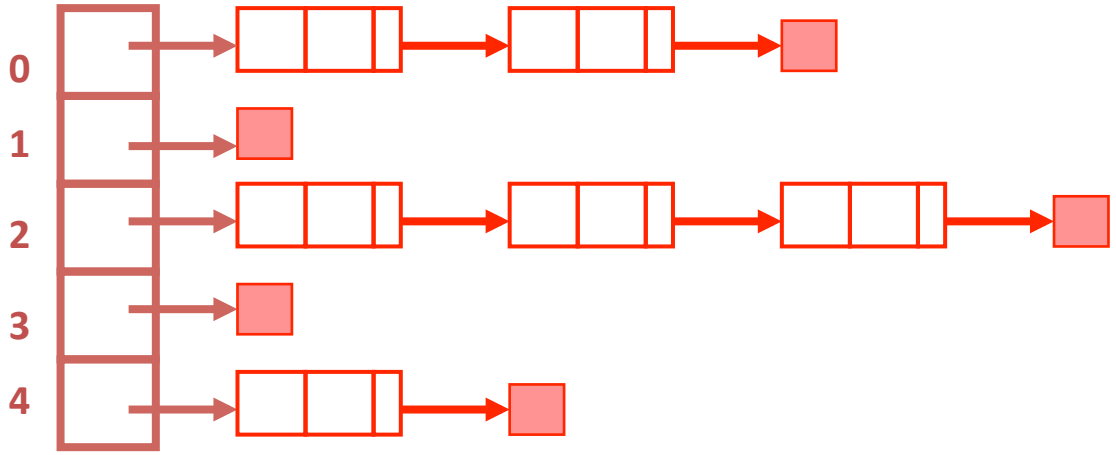


Collisions Resolution

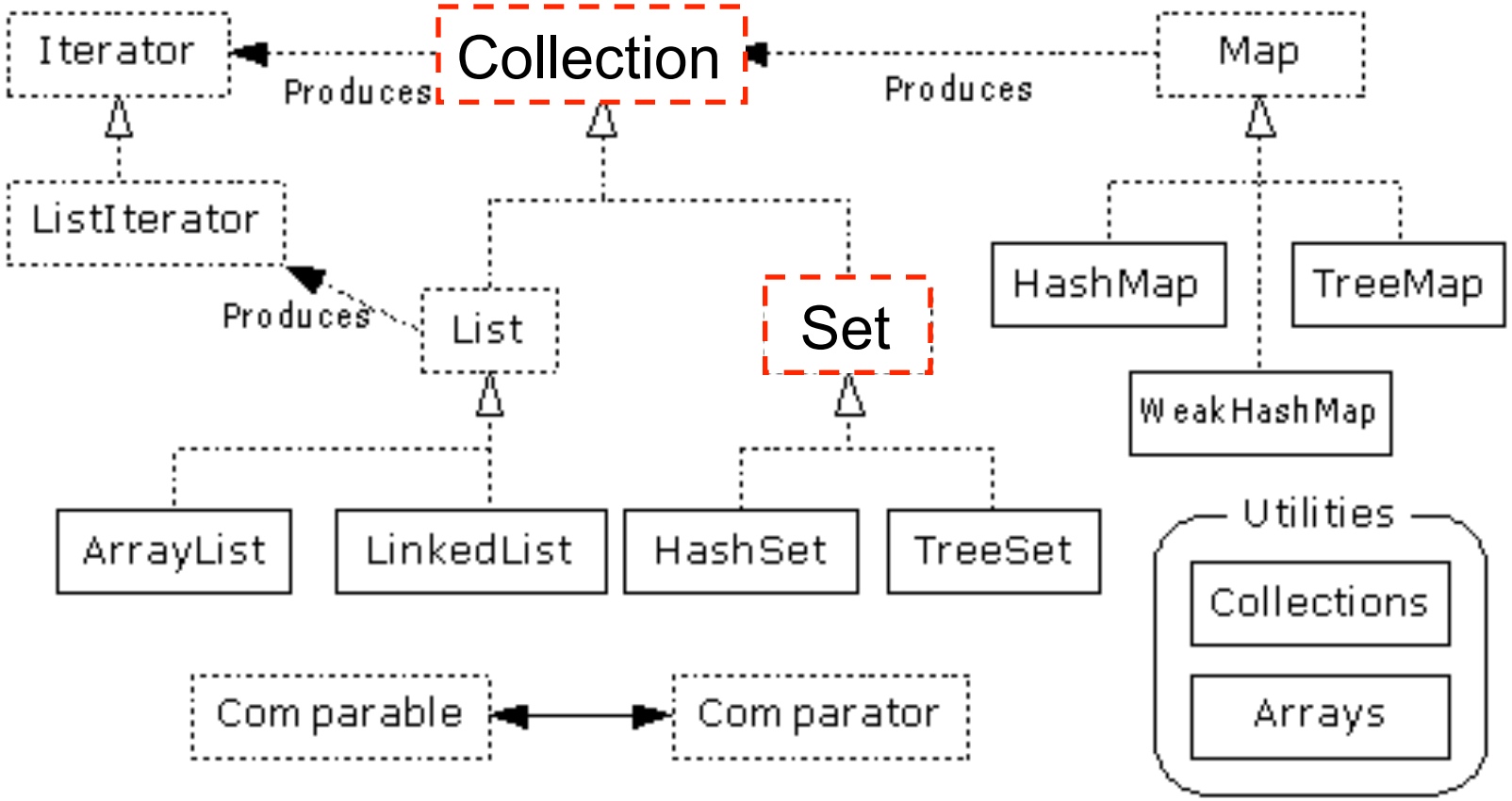
There are two general approaches to resolving collisions:

2. **Chaining (or buckets):** keep a collection at each table entry

   Each position is viewed as a container of a list of items, not a single item. All items in this list share the same hash value



Set Interface Context

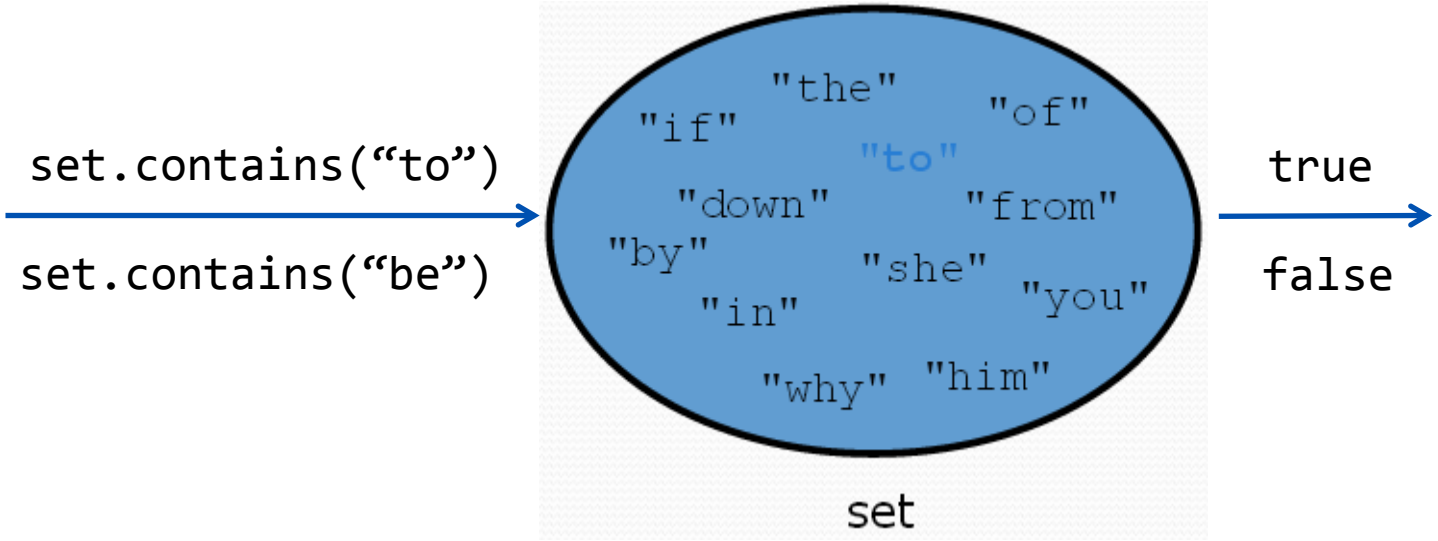


Set Interface

Set is a collection of unique values (no duplicates allowed) that can perform the following operations efficiently:

- add, remove, search (contains)

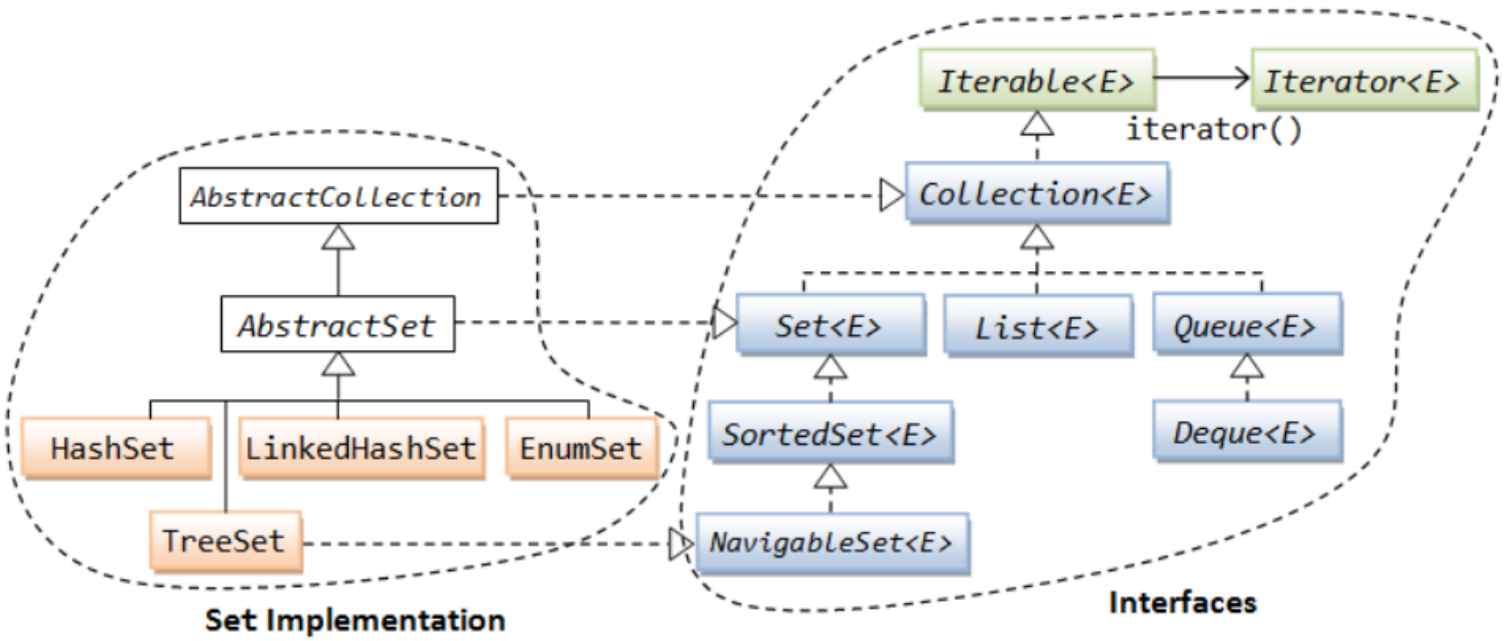
We don't think of a set as having indexes; we just add things to the set in general and don't worry about order



Provides an Iterator to step through the elements in the Set

- No guaranteed order in the basic Set interface
- There is a SortedSet interface that extends Set

Set<E> Interfaces



The Set<E> interface abstract methods:

```
boolean add(E o)            //add the specified element if it is not already present
boolean remove(Object o)    // remove the specified element if it is present
boolean contains(Object o)  // return true if it contains o

// Set operations
boolean addAll(Collection<? extends E> c)      //Set union
boolean retainAll(Collection<?> c)             //Set intersection
```

Set<E> Implementations

- In Java, sets are represented by Set type in java.util

Set is implemented by:

- **HashSet:** implemented using a "hash table" an array of linked lists
  - elements are stored in unpredictable order

- **TreeSet:** implemented using a ”red black tree“
  - elements are stored in sorted order

- **LinkedHashSet:** stores the elements in a linked-list hash table
  - stores in order of insertion

Set<E> Implementations

```
Set<String> s1 = new HashSet<>();
s1.add("DD");  s1.add("EE"); s1.add("BB");  s1.add("CC");
System.out.println("set s1: " + s1);
```

```
set s1: [DD, EE, BB, CC]
```

```
Set<String> s2 = new TreeSet<>();
s2.add("DD"); s2.add("FF"); s2.add("AA");  s2.add("KK");
s2.add("FF");
System.out.println("set s2: " + s2);

if (s2.retainAll(s1))
  System.out.println("Intersection S1 S2: " + s2);
```

```
set s2: [AA, DD, FF, KK]
```

```
Intersection S1 S2: [DD]
```

TreeSet<E> (SortedSet<E>)

- TreeSet guarantees that all elements are ordered (sorted) at all times
  - **add()** and **remove()** preserve this condition
  - **iterator()** always returns the elements in a specified order
- Two ways of specifying ordering
  - Ensuring elements have natural ordering (**Comparable**)
  - Giving a **Comparator<E>** to the constructor
- **Caution:** TreeSet considers x and y are duplicates if:

  x.compareTo(y) == 0 (or compare(x,y) == 0)

TreeSet construction

```
Set<String> words = new TreeSet<String>();
words.add("Bats");
words.add("Ants");
words.add("Crabs");
for (String word : words) {
   System.out.println(word);
}
```

String has a **natural ordering**, so empty constructor

But CD doesn't, so you must pass in a Comparator to the constructor

```
Set<CD> albums = new TreeSet<CD>(new PriceComparator());
albums.add(new CD("Songs of Innocence","U2",new Money(3,50)));
albums.add(new CD("Overexposed","Maroon 5",new Money(2,80)));
albums.add(new CD("Space Cowboy","Jamiroquai",new Money(5,00)));
albums.add(new CD("Maiden Voyage","Herbie Hancock",new Money(4,00)));
albums.add(new CD("Here's the Deal","Liquid Soul",new Money(2,80)));
System.out.println(albums.size());
for (CD album : albums) {
   System.out.println(album);
}
```

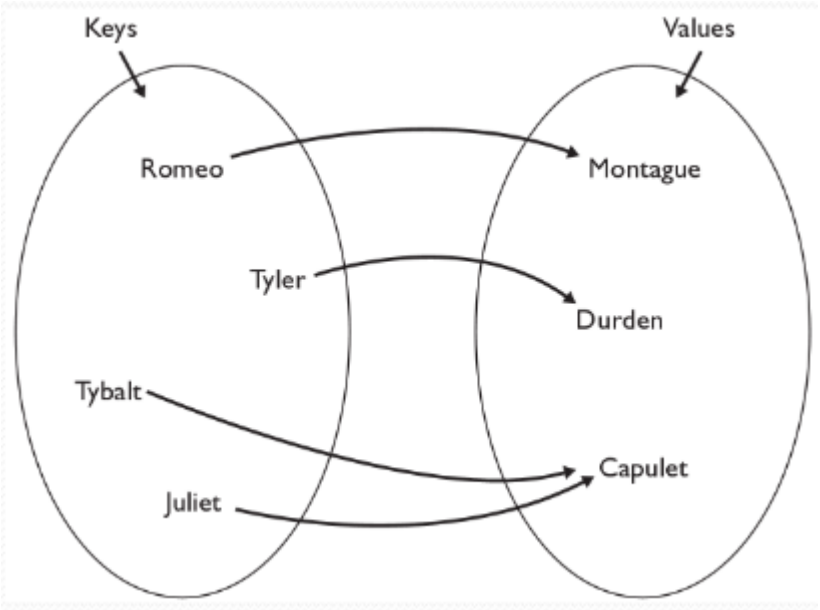
What's the output?

```
4
Maroon 5; U2; Herbie Hancock;
Jamiroquai
```

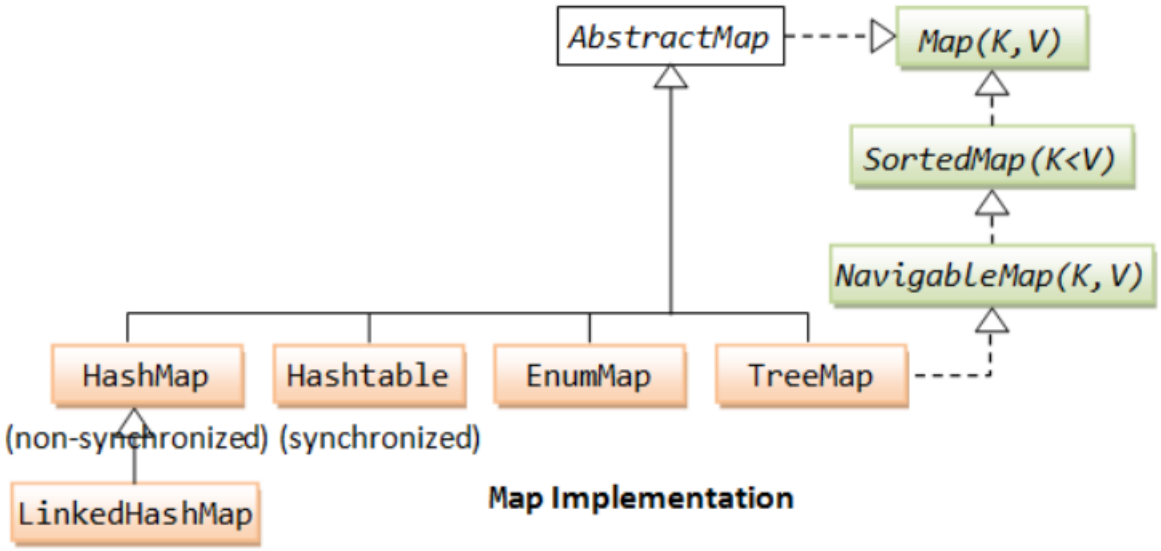
Map

- A **map** is a collection of key-value pairs. Each key maps to one and only value. Duplicate keys are not allowed, but duplicate values are allowed

- Maps are similar to linear arrays, except that an array uses an integer key to index and access its elements; whereas a map uses any arbitrary key (such as Strings or any objects)



Map<K,V> Interfaces



Map<K,V> interface abstract methods:

```
V get(Object key)              //Returns the value of the specified key
put(K key, V value)            //Associates the specified value with the specified key
boolean containsKey(Object key)
boolean containsValue(Object value)

// Views
Set<K> keySet()          // Returns a set view of the keys Collection<V>
values()                 // Returns a collection view of the values Set
entrySet()               // Returns a set view of the key-value
```

Map<K,V> Implementations

in Java, maps are represented by Map type in java.util

Map is implemented by:

- **HashMap:** implemented using an array called a "hash table“
  - keys are stored in unpredictable order

- **TreeMap:** implemented as a linked "binary tree" structure
  - keys are stored in sorted order

- **LinkedHashMap**
  - keys are stored in order of insertion

HashMap<K,V>

- keys are hashed using **Object.hashCode()**
  - i.e. no guaranteed ordering of keys
- **keySet()** returns a **HashSet**
- **values()** returns an unknown Collection

```
Map<String, Integer> directory = new HashMap<String, Integer>();
directory.put("Mum", new Integer(9998888));
directory.put("Dad", 9998888);
directory.put("Bob", 12345678);
directory.put("Edward", 5553535);
directory.put("Bob", 1000000);
System.out.println(directory.size());
for (String key : directory.keySet()) {
  System.out.print(key+"'s number: ");
  System.out.println(directory.get(key));
}
System.out.println(directory.values());
```

TreeMap<K,V>

- Guaranteed ordering of keys (like TreeSet)
  - In fact, TreeSet is implemented using TreeMap
  - Hence **keySet()** returns a **TreeSet**
- **values()** returns an unknown Collection – ordering depends on ordering of **keys**

```
Map<String, Integer> directory = new TreeMap<String, Integer>();
directory.put("Mum", new Integer(9998888));
directory.put("Dad", 9998888);
directory.put("Bob", 12345678);
directory.put("Edward", 5553535);
directory.put("Bob", 1000000);
System.out.println(directory.size());
for (String key : directory.keySet()) {
  System.out.print(key+"'s #: ");
  System.out.println(directory.get(key));
}
System.out.println(directory.values());
```

Empty constructor → natural ordering

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Loop output?

```
Bob's #: 1000000
Dad's #: 9998888
Edward's #: 5553535
Mum's #: 9998888
```

TreeMap with Comparator

As with TreeSet, another way of constructing TreeMap is to give a Comparator necessary for non-Comparable keys

```
Map<CD, Double> ratings
                = new TreeMap<CD, Double>(new PriceComparator());
ratings.put(new CD("Street Signs","O",new Money(3,50)), 8.5);
ratings.put(new CD("Jazzinho","J",new Money(2,80)), 8.0);
ratings.put(new CD("Space Cowboy","J",new Money(5,00)), 9.0);
ratings.put(new CD("Maiden Voyage","H",new Money(4,00)), 9.5);
ratings.put(new CD("Here's the Deal","LS",new Money(2,80)), 9.0);

System.out.println(ratings.size());
for (CD key : ratings.keySet()) {
  System.out.print("Rating for "+key+": ");
  System.out.println(ratings.get(key));
}
System.out.println("Ratings: "+ratings.values());
```

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Ordered by key's price

Depends on key ordering

Double-ended queue or *Deque*

A ***queue*** is a collection whose elements are added and removed in a specific order, typically in a **first-in-first-out (FIFO)** manner

A ***deque*** is a double-ended queue that elements can be inserted and removed at both ends (head and tail) of the queue

A Deque can be used:

- **as FIFO queue** via methods:
  - add(e)/offer(e), remove()/poll(), element()/peek()
- **as LIFO queue** via methods:
  - push(e), pop(), peek()

Queue and Deque implementations

- **PriorityQueue<E>**:

  A queue implemented with a heap where the elements are ordered based on an ordering specified, instead of FIFO

- **ArrayDeque<E>**:

  A queue and deque implemented based on a circular array

- **LinkedList<E>**:

  The LinkedList<E> also implements the Queue<E> and Deque<E> interfaces, in addition to the List<E> interface, providing a queue or deque that is implemented as a double-linked list data structure