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

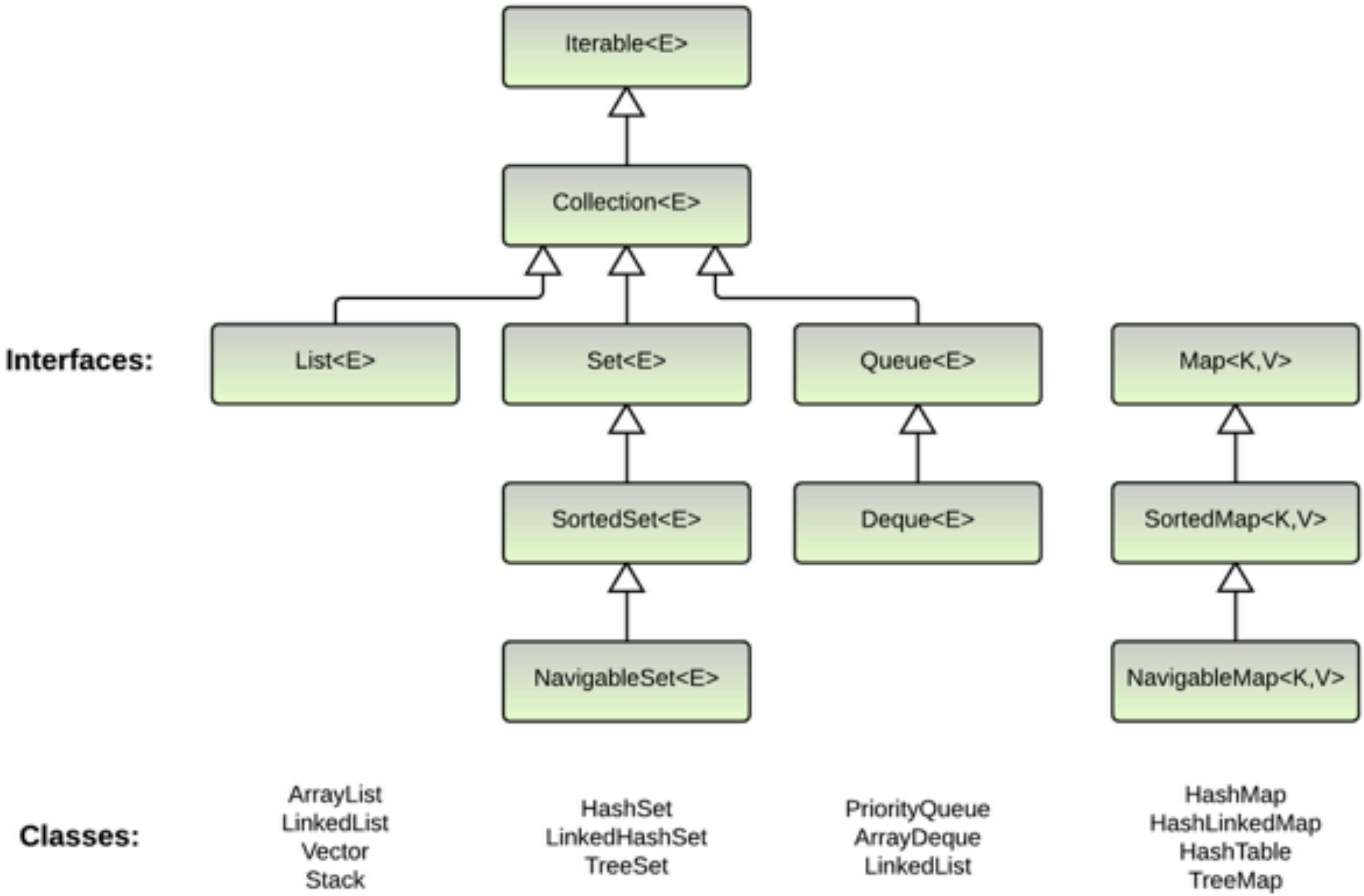
JCF forms part of the **java.util** package and provides:

- interfaces
- abstract classes
- implementations (concrete classes)
- methods for manipulating collections

Offer:

- Standard APIs
- Conversions between structures
- It **reduces the programming effort**, because it offers a lot of code that can be reused

Java Collections Framework



Generics

Generic Class or Parameterized Class

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

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

- With the type parameter, **the *compiler* ensures** that **we use the collection with objects of a compatible type only**
- Object type errors are now detected at **compile time**, rather than throwing casting exceptions at runtime

- Another benefit is that we won't need to cast the objects we get from the collection:

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

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 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)
```

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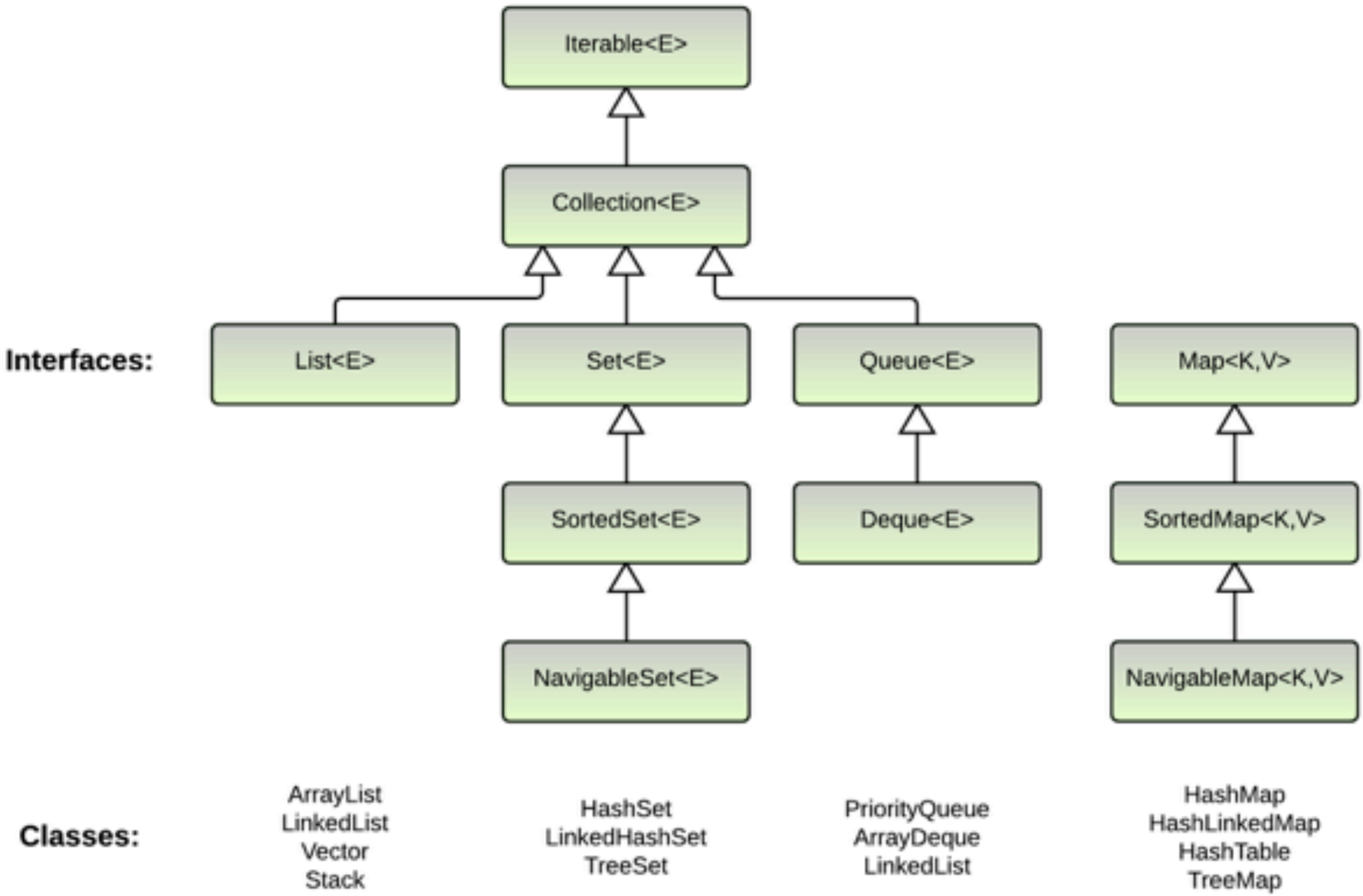
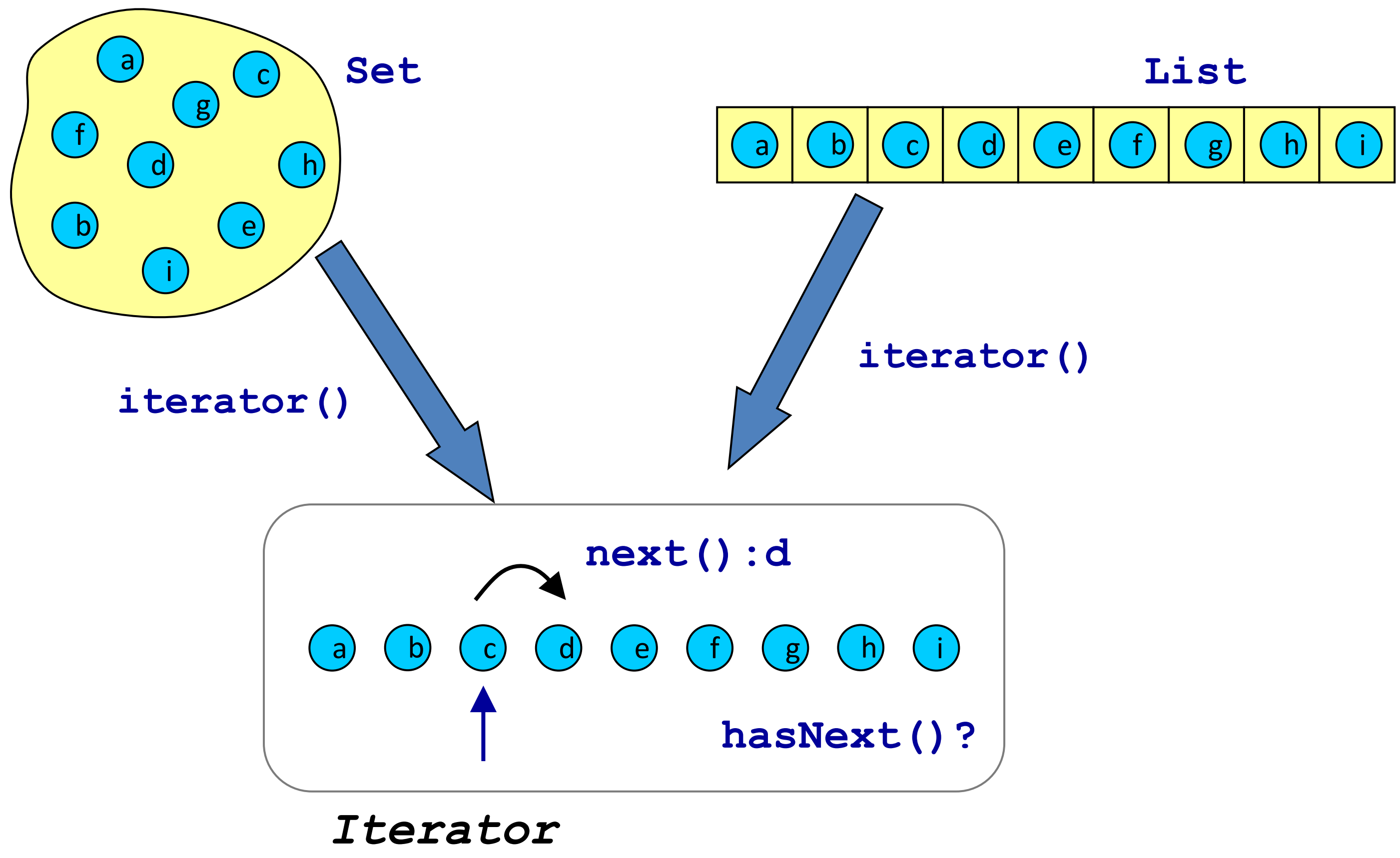


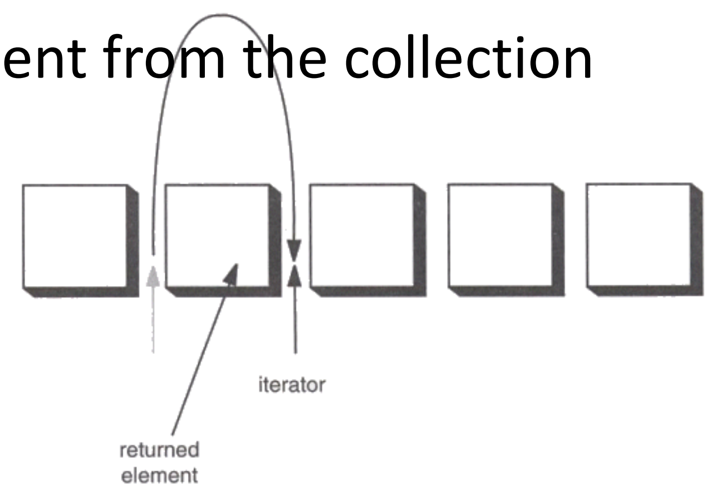
java.util.Iterable<E>

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



Iterator Interface

- Defines three fundamental methods
  - Object next() - returns the next element
  - boolean hasNext() - returns true if there is a next element, otherwise, returns false
  - void remove() – removes it position
- 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<T> content) {
  Iterator<T> it = content.iterator();
  while (it.hasNext()) {
    T item = it.next();
    System.out.println(item);
  }
}
```

<<interface>> **Iterator<E>**
+**hasNext**():boolean +**next**():E +**remove**():void

- 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()

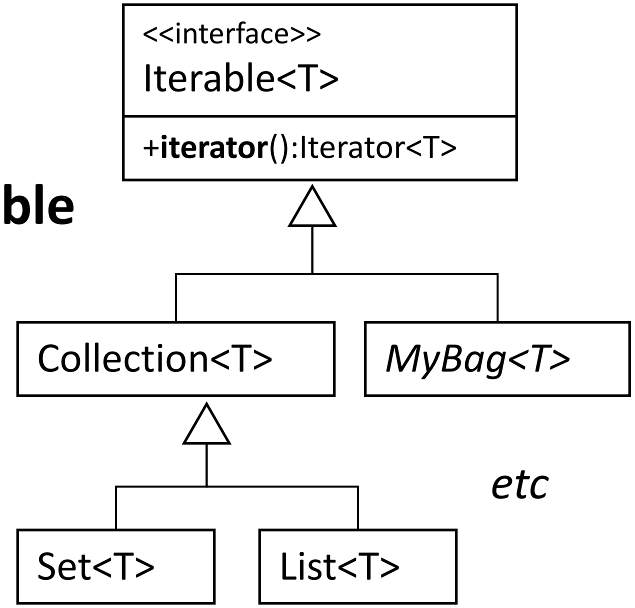
Iterable<T>

```
for (T item : content) {
  System.out.println(item);
}
```

=

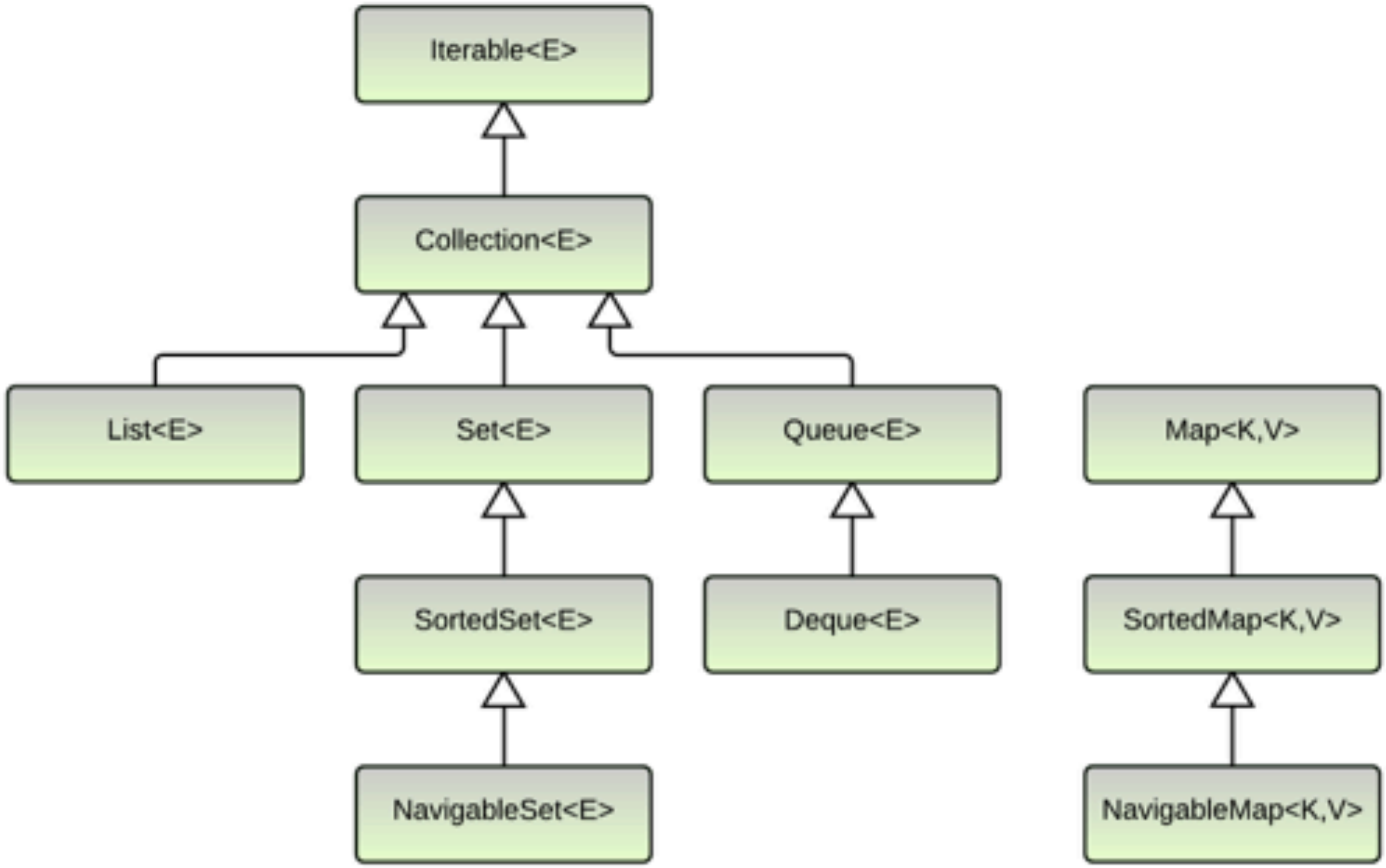
```
Iterator<T> it = items.iterator();
while (it.hasNext()) {
  Item item = it.next();
  System.out.println(item);
}
```

- 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 Collections Framework

Interfaces:



Classes:	ArrayList LinkedList Vector Stack	HashSet LinkedHashSet TreeSet	PriorityQueue ArrayDeque LinkedList	HashMap HashLinkedMap HashTable TreeMap

Collection Interface

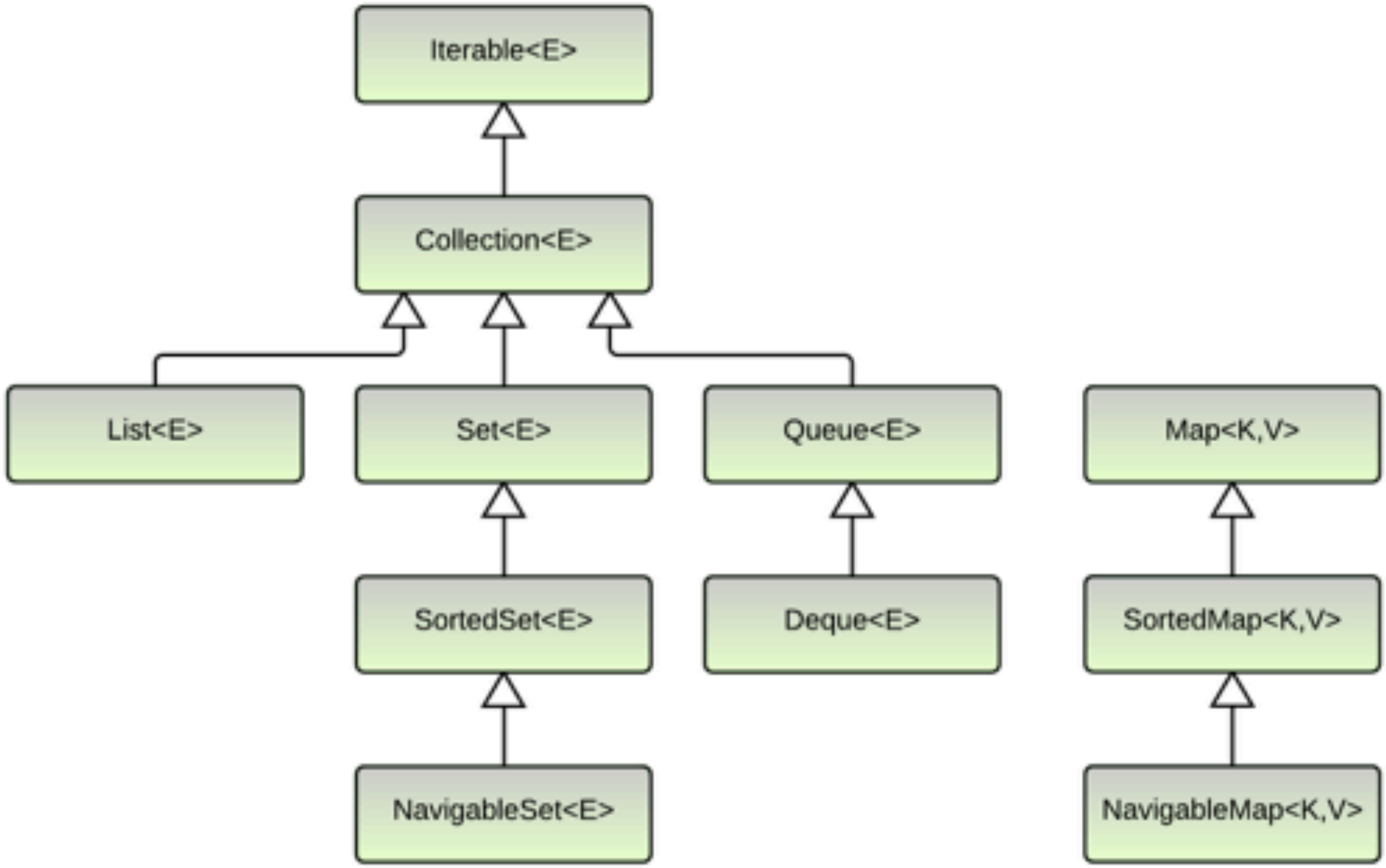
- Defines fundamental methods
  - int size();
  - boolean isEmpty();
  - boolean contains(Object element);
  - boolean add(Object element);   // Optional
  - boolean remove(Object element); // Optional
  - Iterator iterator();
- These methods are enough to define the basic behavior of a collection
-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

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**

Java Collections Framework

Interfaces:



Classes:

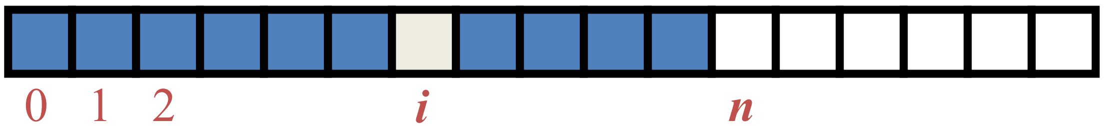
ArrayList LinkedList Vector Stack	HashSet LinkedHashSet TreeSet	PriorityQueue ArrayDeque LinkedList	HashMap HashLinkedMap HashTable TreeMap

List<E> 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

<<interface>> **List<E>**
+**add**(E):boolean +**remove**(Object):boolean +get(int):E +indexOf(Object):int +**contains**(Object):boolean +**size**():int +**iterator**():Iterator<E> etc…

List<E> implementations: ArrayList



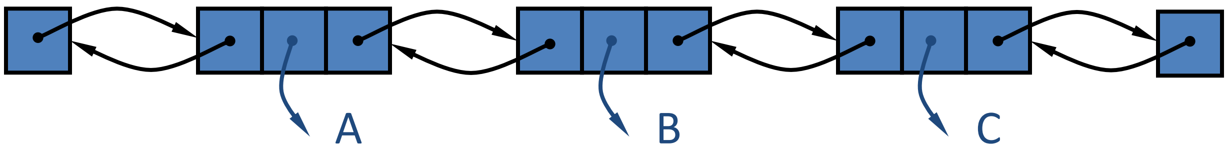
Underlying Data Structure: Resizable array

Performance:

- **Access (get):** Constant time O(1) as it supports random access
- **Insertion**: Generally O(1) when adding at the end (amortized constant time due to resizing), but O(n) if inserting in the middle or resizing the array
- **Deletion:** O(n) for middle and front deletion due to shifting elements

Usage: Best when random access is frequently needed and there are minimal insertions and deletions, especially in the middle of the list.

List<E> implementations: LinkedList



Underlying Data Structure: Doubly-linked list

Performance:

– **Access (get):** Linear time O(n) as it needs to traverse nodes to reach a particular index.

– **Insertion:** Constant time O(1) for adding elements at the beginning or end; O(n) for inserting in the middle (due to traversal).

– **Deletion:** O(1) for removal at the beginning or end; O(n) for removing from the middle (due to traversal).

– **Additional Features:** Implements both List<E> and Deque<E>, meaning it supports operations for both stacks and queues (e.g., poll, peek, offer).

Usage: Best to frequent insertions and deletions, especially at the beginning or end of the list. Not ideal for random access due to O(n) access time

ListIterator Interface

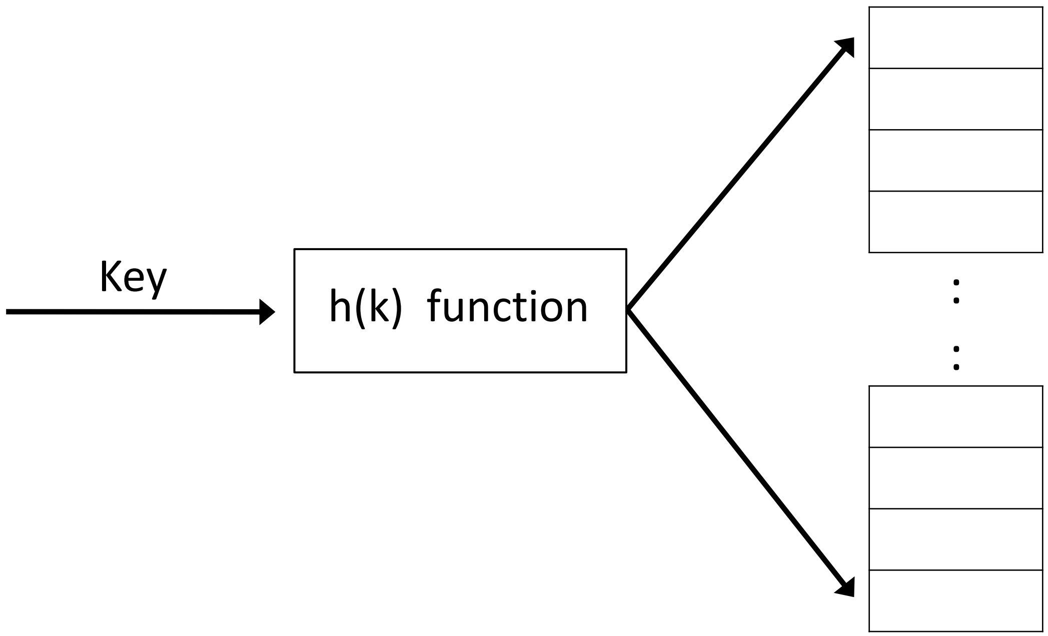
- Extends the Iterator interface
- Defines three fundamental methods
  - void **add(Object o)** - Inserts object into the list in front of it position
  - boolean **hasPrevious()**
  - Object **previous()**
- The addition of these three methods defines the basic behavior of an ordered list
- A ListIterator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

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

1. **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**

Collision

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

Alfred	**f = 5 % 8 = 5**
Alessia	**e = 4 % 8 = 4**
Amina	**i = 0 % 8 = 0**
Andy	**d = 3 % 8 = 3**
Aspen	**p = 7 % 8 = 7**
Aimee	**m = 4 % 8 = 4**

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

Amina			Andy	Alessia	Alfred		Aspen
0	1	2	3	4	5	6	7
aiqy	bjrz	cks	dlt	emu	fnv	gpw	hpq

To add: Aimee

Hashes to

Placed here

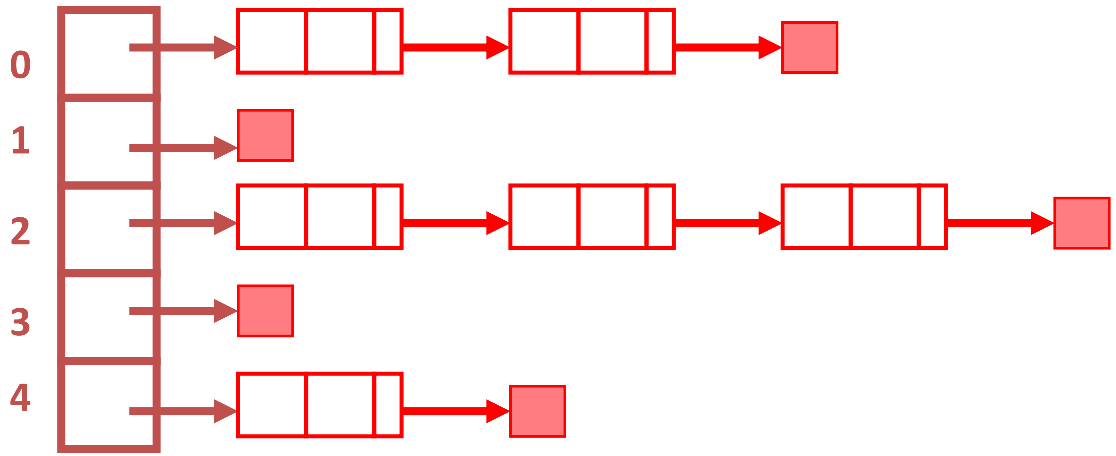
Amina			Andy	Alessia	Alfred	Aimee	Aspen
0	1	2	3	4	5	6	7
aiqy	bjrz	cks	dlt	emu	fnv	gpw	hpq

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



Java Hash function

- Java provides a suitable hash function hashCode() defined in **Object class** and inherited by all subclasses, which typically returns the 32-bit memory address of the object
- If a class **overrides the equals method** defined in class Object it is also necessary to **override the hashCode** method to make **HashSet and HashMap** work correctly
- **The hashCode() method should be suitably redefined by classes**

Java Hash function

```
class IntBox {
    Integer i;
    IntBox(Integer i) { this.i = i; }

    // equals other IntBoxes that store the same int value.
    @Override
    public boolean equals(Object o) {
        IntBox other = (IntBox) o;
        return this.i == other.i;
    }
}
```

```
class main {
    public static void main(String[] args) {
        Set<IntBox> intBoxes = new HashSet<>();
        intBoxes.add(new IntBox(0));
        boolean found = intBoxes.contains(new IntBox(0));
        // found == false
    }
}
```

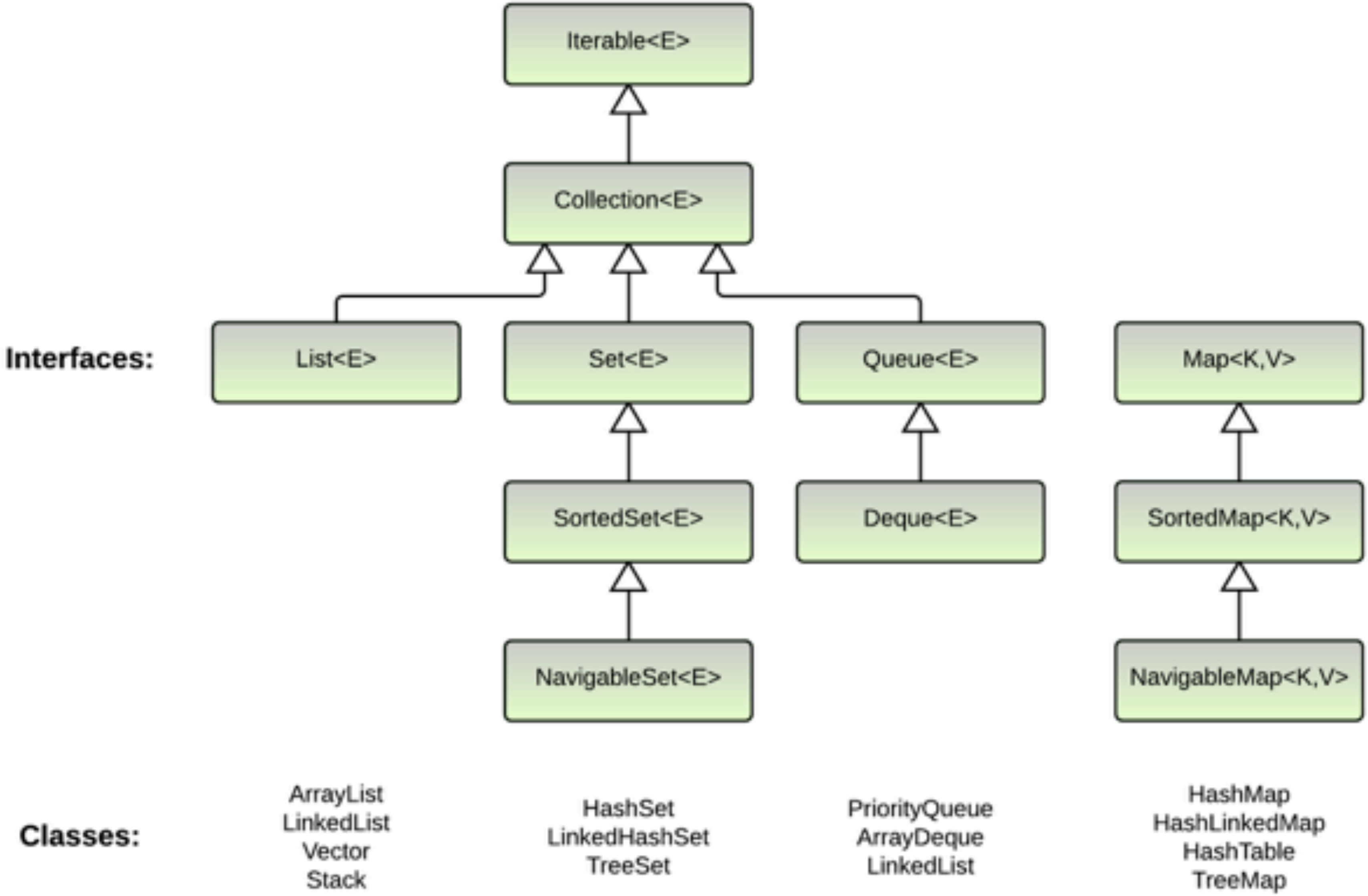
Java Hash function

```
class IntBox {
    Integer i;
    IntBox(Integer i) { this.i = i; }

    // equals other IntBoxes that store the same int value.
    @Override
    public boolean equals(Object o) {
        IntBox other = (IntBox) o;
        return this.i == other.i;
    }

    @Override
    public int hashCode() {
        return this.i.hashCode();
    }
}
```

Java Collections Framework

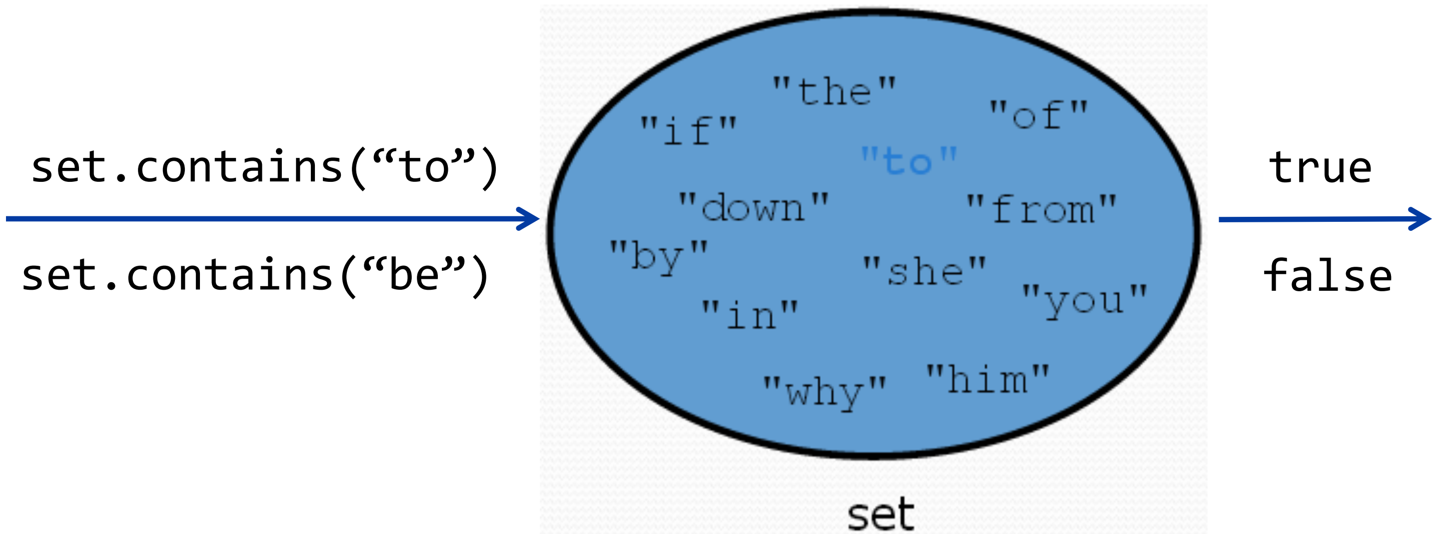


Set<E> Interface

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

- add, remove, search (contains)

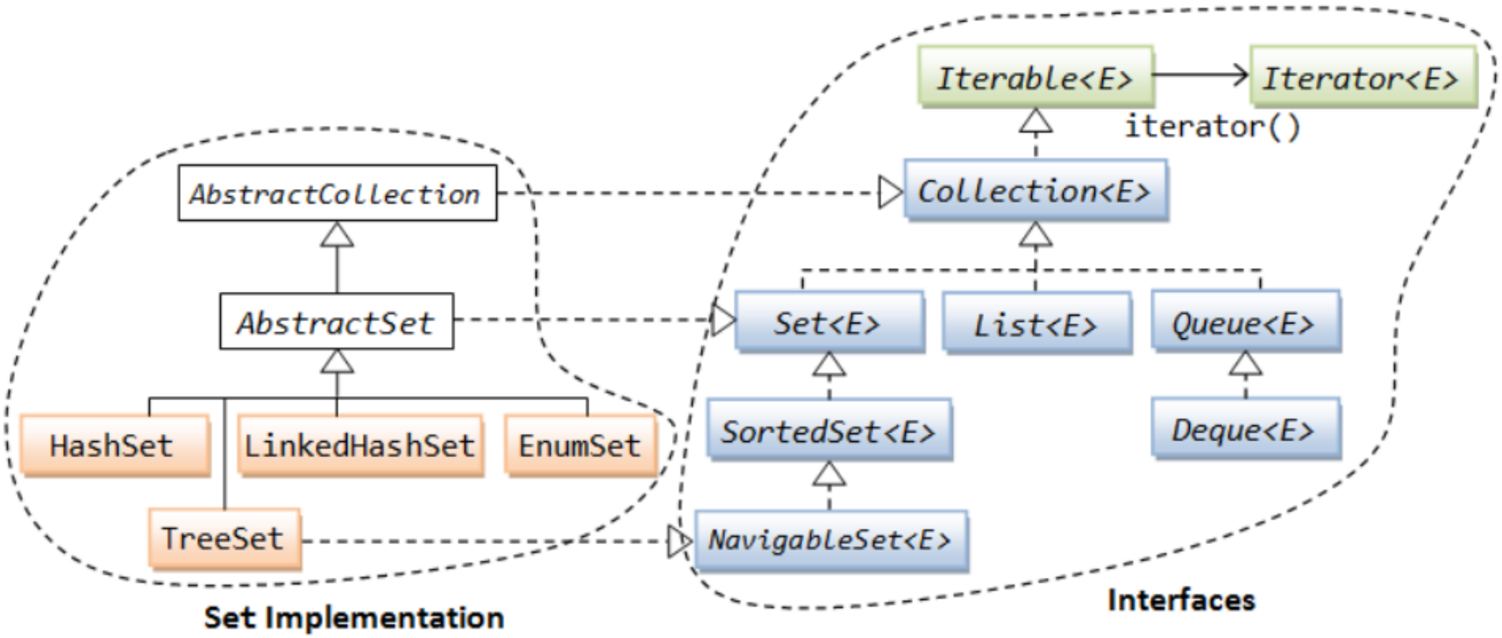
We don't think of a set as having indexes; we just add things to the set in general and don't worry about order



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> Interface



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
boolean removeAll(Collection<?> c)               //Set difference
```

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

```
Set<String> s2 = new LinkedHashSet<>();
s2.add("DD");  s2.add("EE"); s2.add("BB");  s2.add("CC");
System.out.println("set s2: " + s2);
```

```
set s2: [DD, EE, BB, CC]
```

```
Set<String> s3 = new TreeSet<>();
s3.add("DD"); s3.add("FF"); s3.add("AA");  s3.add("KK");
s3.add("FF"); s3.add(”EE");
System.out.println("set s3: " + s3);
```

```
set s3: [AA, DD, EE, FF, KK]
```

```
if (s3.retainAll(s1))
  System.out.println("Intersection S1 S3: " + s3);
```

```
Intersection S1 S3: [DD, EE]
```

`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<>();
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(“N. CDs “+albums.size());
for (CD album : albums) {
  System.out.println(album);
}
```

What's the output?

```
N. CDs 4
Maroon 5 (2.8); U2(3.5); Herbie
Hancock (4.0); Jamiroquai (5.0)
```

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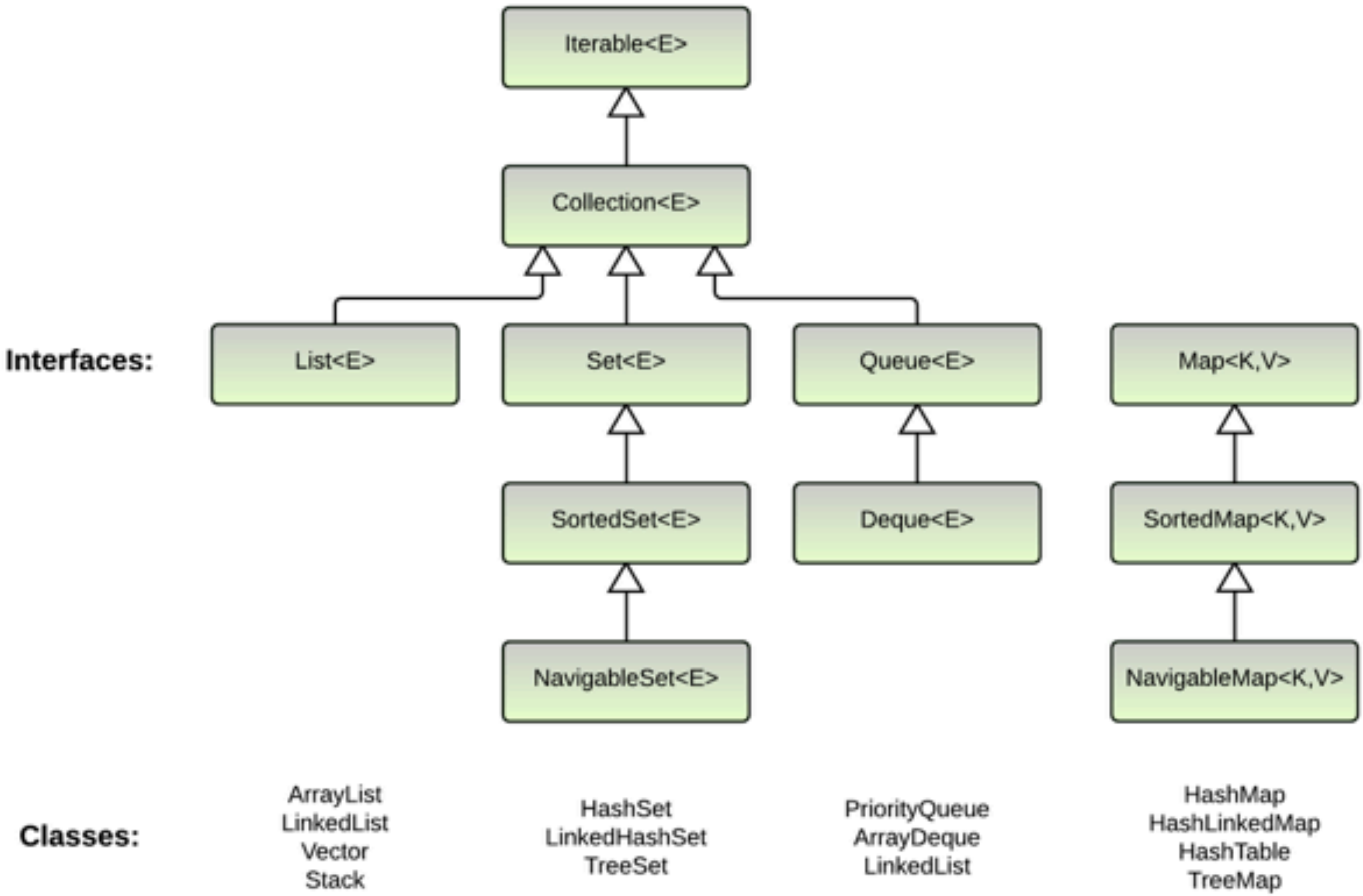
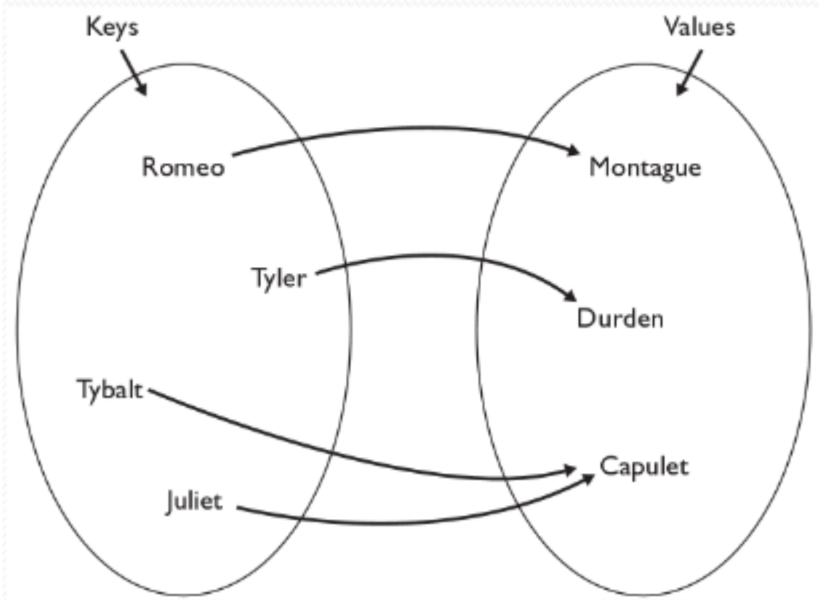


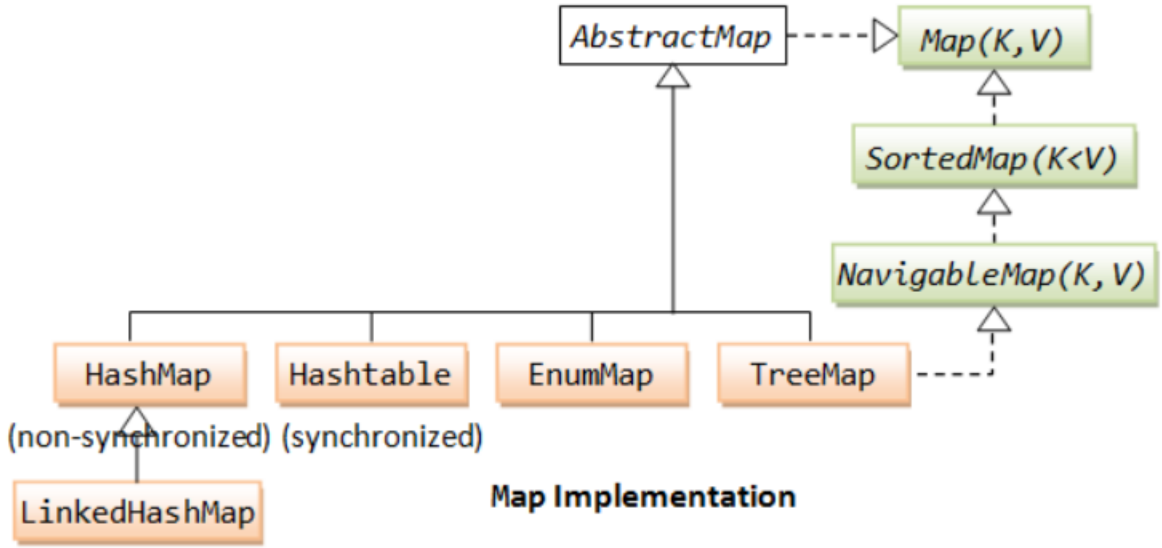
Interface Map<K,V>

- 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“
  - no guarantees about the iteration order. It can (and will) even change completely when new elements are added
- **TreeMap:** implemented as a linked "binary tree" structure
  - will iterate according to the "natural ordering" of the key, ie. according to their compareTo() method (or an externally supplied Comparator)
- **LinkedHashMap**
  - will iterate in the order in which the entries were put into the map

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.println(key+"'s number: ”, 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**

Empty constructor
→ natural ordering

```
Map<String, Integer> directory = new TreeMap<>();
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 (Entry<String, String> entry : directory.entrySet())
  System.out.print(entry.getKey()+"'s #: ", entry.getValue());
System.out.println(directory.values());
```

4

```
[1000000,9998888,5553535,
9998888]
```

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<>(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());
```

4

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