Java Collections Framework

Object Oriented Programming

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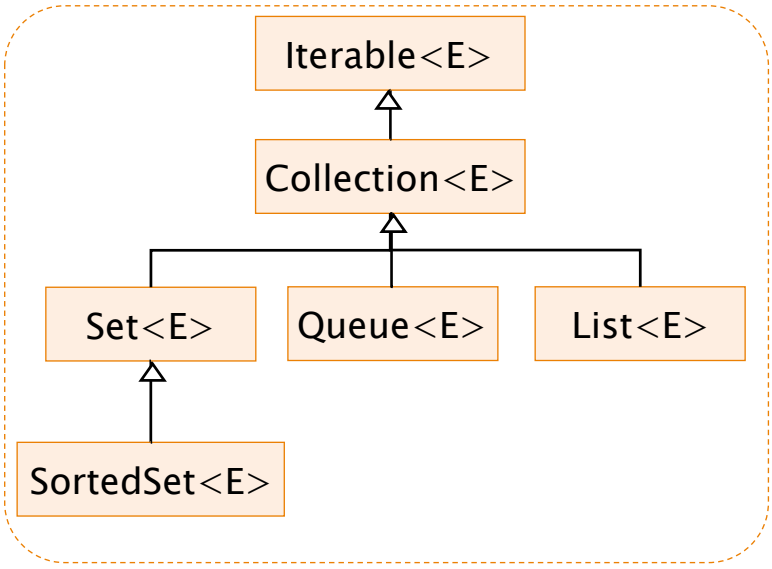
Licensing Note

Framework

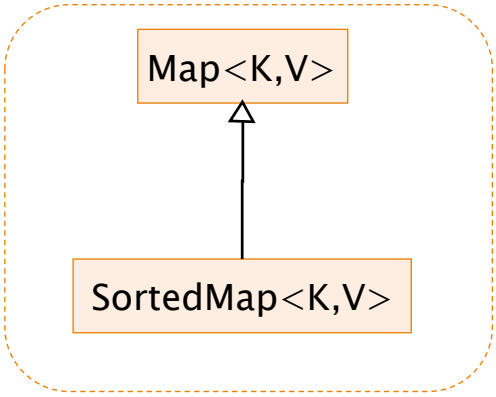
- Interfaces (ADT, Abstract Data Types)
- Implementations (of ADT)
- Algorithms (sort)
- Contained in the package `java.util`

- Originally using Object, since Java 5 redefined as generic

Interfaces

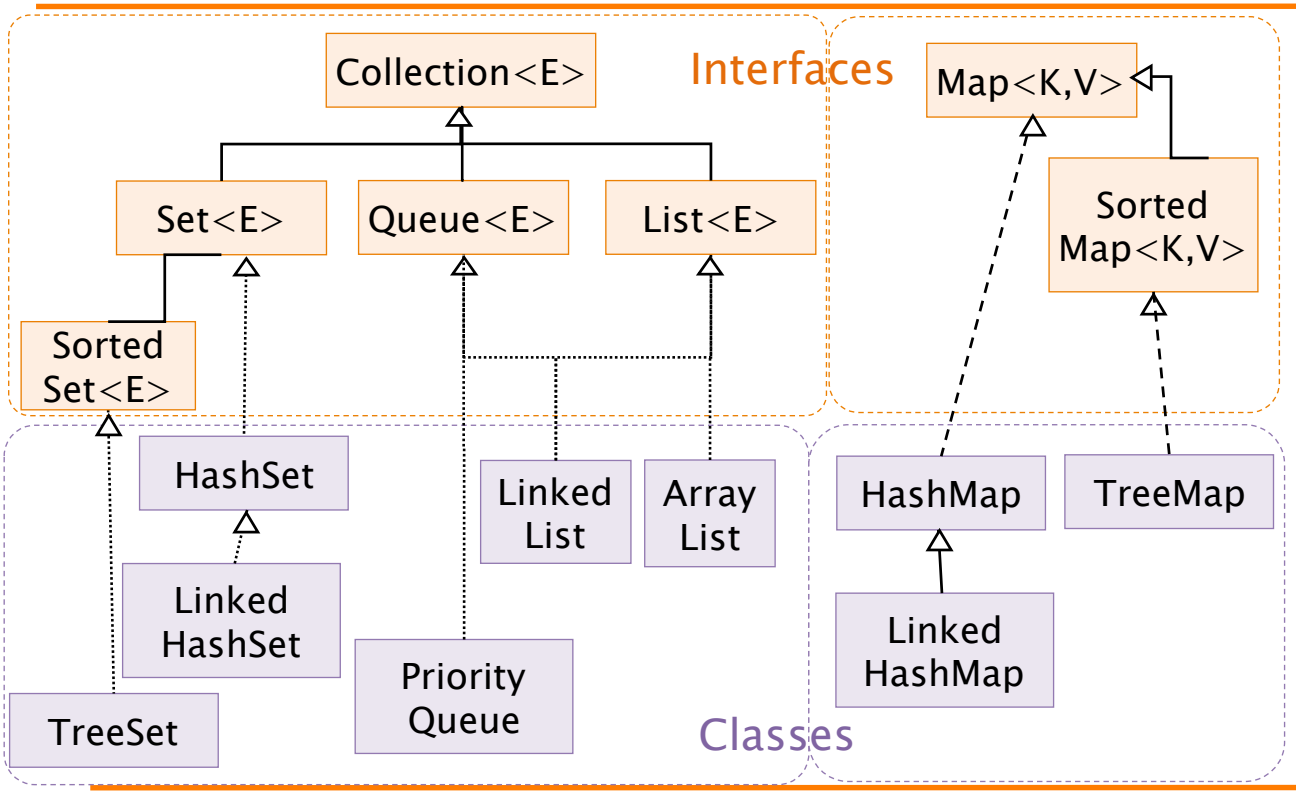


Group containers



Associative containers

Implementations



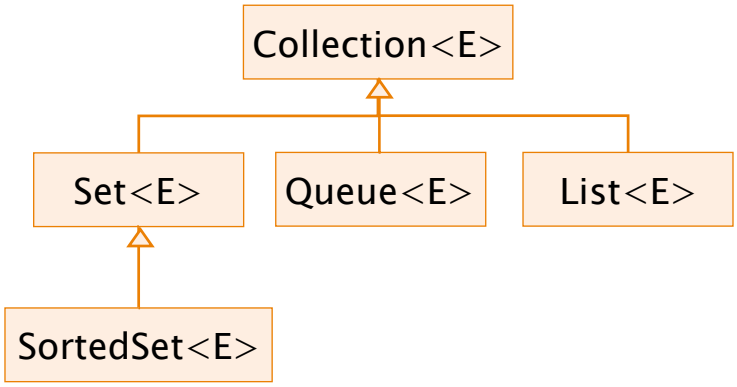
Internals

data structure

	Hash table	Balanced tree	Resizable array	Linked list	HT + LL
Set	`HashSet`	`TreeSet`			`LinkedHashSet`
List			`ArrayList`	`LinkedList`	
Map	`HashMap`	`TreeMap`			`LinkedHashMap`

interface

classes



GROUP CONTAINERS (COLLECTIONS)

Collection

- Group of elements (references to objects)
- It is not specified whether they are
  - Ordered / not ordered
  - Duplicated / not duplicated
- Implements `Iterable`
- Two constructors common to all classes implementing Collection
  - `C()`
  - `C(Collection c)`

Collection interface

```
int size()
boolean isEmpty()
boolean contains(E element)
boolean containsAll(Collection<?> c)
boolean add(E element)
boolean addAll(Collection<? extends E> c)
boolean remove(E element)
boolean removeAll(Collection<?> c)
void clear()
Object[] toArray()
Iterator<E> iterator()
```


Collection example

```
Collection<Person> persons =
                    new LinkedList<Person>();
persons.add( new Person("Alice") );
System.out.println( persons.size() );
Collection<Person> copy =
                    new TreeSet<Person>();
copy.addAll(persons);//new TreeSet(persons)
Person[] array = copy.toArray();
System.out.println( array[0] );
```

List

- Can contain duplicate elements
- Insertion order is preserved
- User can define insertion point
- Elements can be accessed by position
- Augments Collection interface

List interface

```
E get(int index)
E set(int index, E element)
void add(int index, E element)
E remove(int index)

boolean addAll(int index,Collection<E> c)
int indexOf(E o)
int lastIndexOf(E o)
List<E> subList(int from, int to)
```

`List` implementations

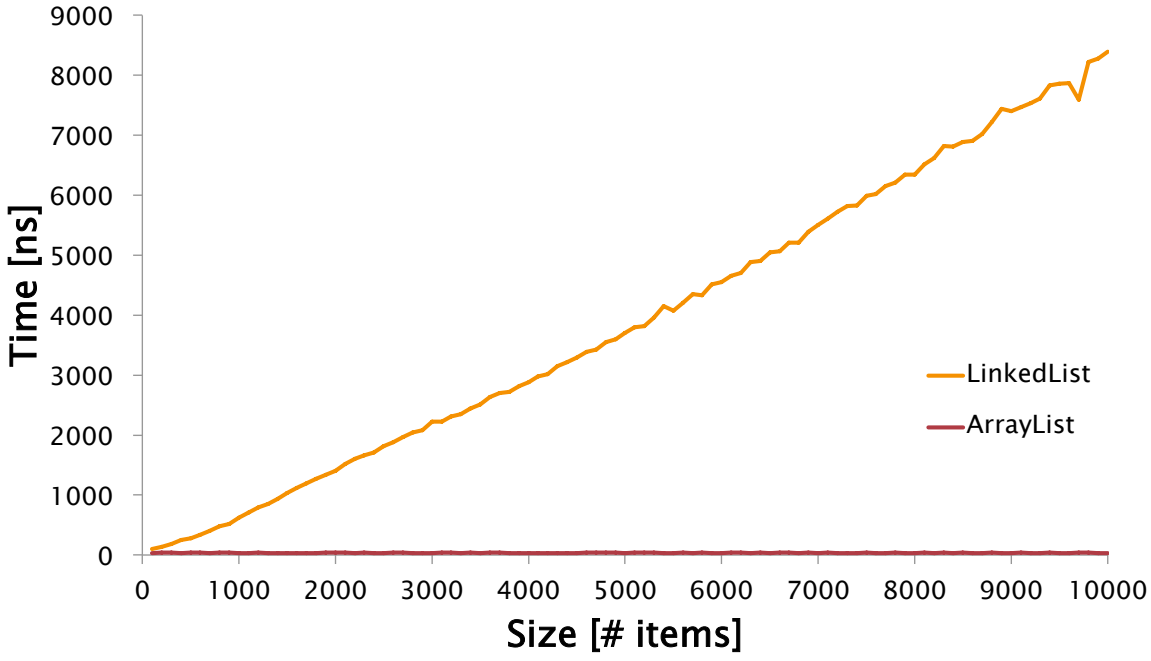
`ArrayList`

- `get(n)`
  - Constant
- `add(0,…)`
  - Linear
- `add()`
  - Constant

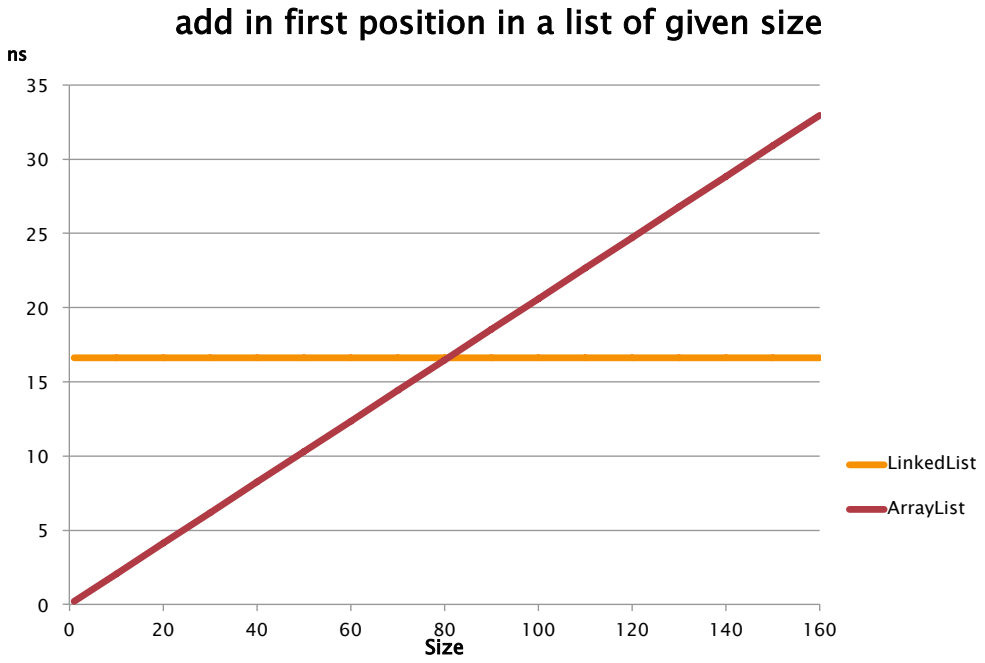
`LinkedList`

- `get(n)`
  - Linear
- `add(0, … )`
  - Constant
- `add()`
  - Constant

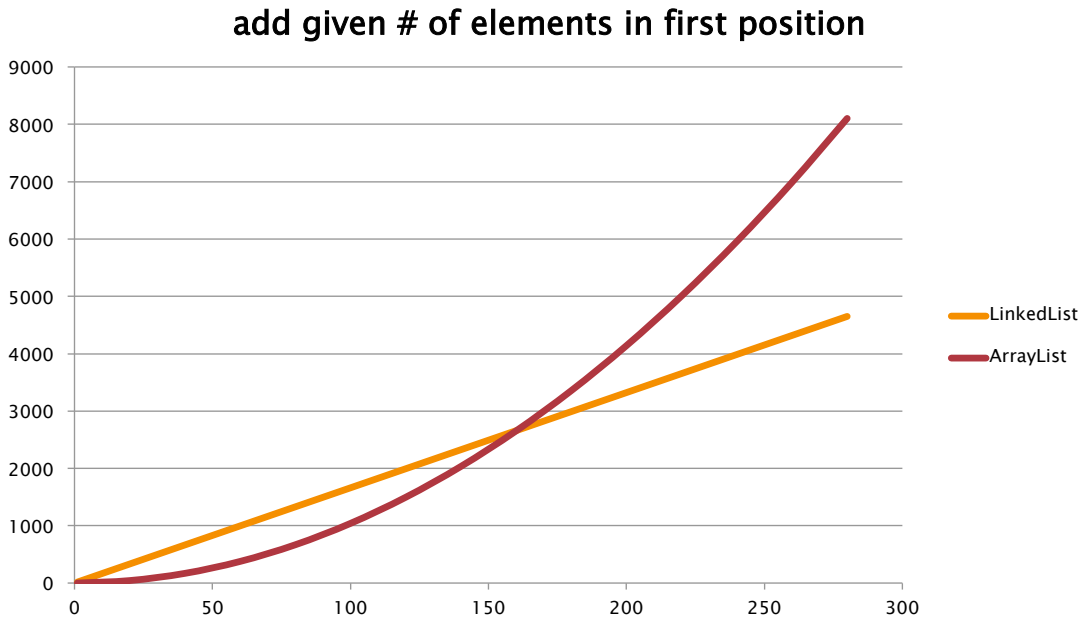
`List` implementations – Get



`List` Implementations – Add



`List` Implementations – Add



`List` implementation – Models

	`LinkedList`	`ArrayList`
Add in first pos. in list of size *n*	$t(n) = C_L$	$t(n) = n \cdot C_A$
Add *n* elements	$t(n) = n \cdot C_L$	$t(n) = \sum_{i=1}^{n} C_A \cdot i = \frac{C_A}{2} n \cdot (n-1)$

$C_L = 16.0$ ns
$C_A = 0.2$ ns

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`List` implementations

- `ArrayList<E>`
  - `ArrayList()`
  - `ArrayList(int initialCapacity)`
  - `ArrayList(Collection<E> c)`
  - `void ensureCapacity(int minCapacity)`
- `LinkedList<E>`
  - `void addFirst(E o)`
  - `void addLast(E o)`
  - `E getFirst()`
  - `E getLast()`
  - `E removeFirst()`
  - `E removeLast()`

Example I

```
LinkedList<Integer> ll =
            new LinkedList<Integer>();

ll.add(new Integer(10));
ll.add(new Integer(11));

ll.addLast(new Integer(13));
ll.addFirst(new Integer(20));

//20, 10, 11, 13
```


Example II

```
Car[] garage = new Car[20];

garage[0] = new Car();
garage[1] = new ElectricCar();
garage[2] =
garage[3] =

for(int i=0;
   garage[i]
}
```

```
List<Car> garage = new ArrayList<Car>(20);

garage.set( 0, new Car() );
garage.set( 1, new ElectricCar() );
garage.set( 2, new ElectricCar() );
garage.set( 3, new Car());

for(int i; i<garage.size(); i++){
   Car c = garage.get(i);
   c.turnOn();
}
```

Example III

```
List l = new ArrayList(2); // 2 refs to null

l.add(new Integer(11));    // 11 in position 0
l.add(0, new Integer(13)); // 11 in position 1
l.set(0, new Integer(20)); // 13 replaced by 20

l.add(9, new Integer(30));  // NO: out of bounds
l.add(new Integer(30));     // OK, size extended
```


`Queue` interface

- Collection whose elements have an order
  - not and ordered collection though
- Defines a head position where is the first element that can be accessed
  - `peek()`
  - `poll()`

`Queue` implementations

- **`LinkedList`**
  - head is the first element of the list
  - FIFO: Fist-In-First-Out
- **`PriorityQueue`**
  - head is the smallest element

`Queue` example

```
Queue<Integer> fifo =
               new LinkedList<Integer>();
Queue<Integer> pq =
               new PriorityQueue<Integer>();
fifo.add(3); pq.add(3);
fifo.add(1); pq.add(1);
fifo.add(2); pq.add(2);
System.out.println(fifo.peek()); // 3
System.out.println(pq.peek());   // 1
```

`Set` interface

- Contains no methods
  - Only those inherited from `Collection`
- `add()` has the restriction that no duplicate elements are allowed
  - `e1.equals(e2) == false` $\forall$ e1,e2 $\in \Sigma$
- Iterator
  - The elements are traversed in no particular order

`SortedSet` interface

- No duplicate elements
- Iterator
  - The elements are traversed according to the natural ordering (ascending)
- Augments Set interface
  - `Object first()`
  - `Object last()`
  - `SortedSet headSet(Object toElement)`
  - `SortedSet tailSet(Object fromElement)`
  - `SortedSet subSet(Object from, Object to)`

`Set` implementations

- `HashSet` implements `Set`
  - Hash tables as internal data structure (faster)
- `LinkedHashSet` extends `HashSet`
  - Elements are traversed by iterator according to the insertion order
- `TreeSet` implements `SortedSet`
  - R-B trees as internal data structure (computationally expensive)

Note on sorted collections

- Depending on the constructor used they require different implementation of the custom ordering
- `TreeSet()`
  - Natural ordering (elements must be implementations of Comparable)
- `TreeSet(Comparator c)`
  - Ordering is according to the comparator rules, instead of natural ordering

Generic collections

- Since Java 5, all collection interfaces and classes have been redefined as Generics
- Use of generics leads to code that is
  - safer
  - more compact
  - easier to understand
  - equally performing

Object list – excerpt

```
public interface List{
  void add(Object x);
  Object get(int i);
  Iterator<E> iterator();
}
public interface Iterator{
  Object next();
  boolean hasNext();
}
```

Example

- Using a list of Integers
  - Without generics (`ArrayList list`)

```
list.add(0, new Integer(42));
int n= ((Integer)(list.get(0))).intValue();
```

  - With generics (`ArrayList<Integer> list`)

```
list.add(0, new Integer(42));
int n= ((Integer)(list.get(0))).intValue();
```

  - + autoboxing (`ArrayList<Integer> list`)

```
list.add(0,new Integer(42));
int n = ((Integer)(list.get(0))).intValue();
```


ITERATORS

`Iterable` interface

- Container of elements that can be iterated upon
- Provides a single method:

  ```
  Iterator<E> iterator()
  ```

  - It returns the iterator on the elements of the collection
- Collection extends Iterable

Iterators and iteration

- A common operation with collections is to iterate over their elements
- Interface Iterator provides a transparent means to cycle through all elements of a Collection
- Keeps track of last visited element of the related collection
- Each time the current element is queried, it moves on automatically

Iterator

- Allows the iteration on the elements of a collection
- Two main methods:
  - **`boolean hasNext()`**
    - Checks if there is a next element to iterate on
  - **`E next()`**
    - Returns the next element and advances by one position
  - **`void remove()`**
    - Optional method, removes the current element

Iterator examples

Print all objects in a list

```
Iterable<Person> persons =
                    new LinkedList<Person>();
…
for(Iterator<Person> i = persons.iterator();
                                 i.hasNext(); ) {
    Person p = i.next();
    …
   System.out.println(p);
}
```

Iterator examples

The for-each syntax avoids using iterator directly

```
Iterable<Person> persons =
                    new LinkedList<Person>();
…
for(Person p: persons) {
    …
   System.out.println(p);
}
```


Iterator examples (until Java 1.4)

Print all objects in a list

```
Collection persons = new LinkedList();
…
for(Iterator i= persons.iterator(); i.hasNext(); ) {
    Person p = (Person)i.next();
    …
}
```

Iterable `forEach`

- Iterable defines the default method

  `forEach(Consumer<? super T> action)`

- Can be used to perform operations of elements with a functional interface

```
Iterable<Person> persons =
                    new LinkedList<Person>();
…
persons.forEach( p -> {
   System.out.println(p);
}
```


Note well

- It is unsafe to iterate over a collection you are modifying (add/remove) at the same time

- Unless you are using the iterator's own methods
  - `Iterator.remove()`
  - `ListIterator.add()`

Delete

```
List<Integer> lst=new LinkedList<Integer>();
lst.add(new Integer(10));
lst.add(new Integer(11));
lst.add(new Integer(13));
lst.add(new Integer(20));

int count = 0;
for (Iterator<?> itr = lst.iterator();
                              itr.hasNext(); ) {
   itr.next();
   if (count==1)
      lst.remove(count); // wrong
   count++;
}
```

ConcurrentModificationException

Delete (cont'd)

```
List<Integer> lst=new LinkedList<Integer>();
lst.add(new Integer(10));
lst.add(new Integer(11));
lst.add(new Integer(13));
lst.add(new Integer(20));

int count = 0;
for (Iterator<?> itr = lst.iterator();
                        itr.hasNext(); ) {
   itr.next();
   if (count==1)
      itr.remove(); // ok
   count++;
}
```

Correct

Add

```
List lst = new LinkedList();
lst.add(new Integer(10));
lst.add(new Integer(11));
lst.add(new Integer(13));
lst.add(new Integer(20));

int count = 0;
for (Iterator itr = lst.iterator();
                          itr.hasNext(); ) {
   itr.next();
   if (count==2)
     lst.add(count, new Integer(22));//wrong
   count++;
}
```

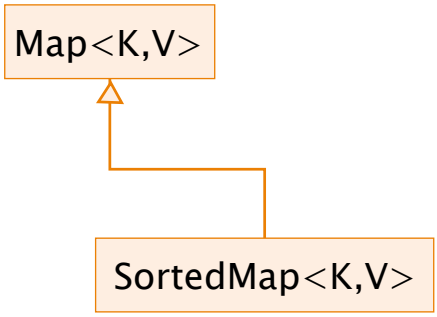
ConcurrentModificationException

Add (cont'd)

```
List<Integer> lst=new LinkedList<Integer>();
lst.add(new Integer(10));
lst.add(new Integer(11));
lst.add(new Integer(13));
lst.add(new Integer(20));

int count = 0;
for (ListIterator<Integer> itr =
        lst.listIterator(); itr.hasNext();){
   itr.next();
   if (count==2)
      itr.add(new Integer(22)); // ok
   count++;
}
```

Correct



ASSOCIATIVE CONTAINERS (MAPS)

Map

- A container that associates keys to values (e.g., SSN ⇒ Person)
- Keys and values must be objects
- Keys must be unique
  - Only one value per key
- Following constructors are common to all collection implementers
  - `M()`
  - `M(Map m)`

Map interface

- V put(K key, V value)
- V get(K key)
- Object remove(K key)
- boolean containsKey(K key)
- boolean containsValue(V value)
- public Set<K> keySet()
- public Collection<V> values()
- int size()
- boolean isEmpty()
- void clear()

Map example

```
Map<String,Person> people =new HashMap<>();
people.put( "ALCSMT", //ssn
   new Person("Alice", "Smith") );
people.put( "RBTGRN", //ssn
   new Person("Robert", "Green") );

Person bob = people.get("RBTGRN");
if( bob == null )
  System.out.println( "Not found" );

int populationSize = people.size();
```

`SortedMap` interface

- The elements are traversed according to the keys' natural ordering (ascending)
- Augments **`Map`** interface
  - `SortedMap subMap(K fromKey, K toKey)`
  - `SortedMap headMap(K toKey)`
  - `SortedMap tailMap(K fromKey)`
  - `K firstKey()`
  - `K lastKey()`

`Map` implementations

- Analogous to Set
- **`HashMap`** implements **`Map`**
  - No order
- **`LinkedHashMap`** extends **`HashMap`**
  - Insertion order
- **`TreeMap`** implements **`SortedMap`**
  - Ascending key order

HashMap

- Get/put takes constant time (in case of no collisions)
- Automatic re-allocation when load factor reached
- Constructor optional arguments
  - load factor (default = .75)
  - initial capacity (default = 16)

Using HashMap

```
Map<String,Student> students =
        new HashMap<String,Student>();

students.put("123",
        new Student("123","Joe Smith"));

Student s = students.get("123");

for(Student si: students.values()){

}
```

TreeMap

- Get/put takes log time
- Based on a Red-Black tree
- Keys are maintained and will be traversed in order
- Constructor optional arguments
  - Comparator to replace the natural order of keys

ALGORITHMS

Algorithms

- Static methods of `java.util.Collections`
  - Work on List since it has the concept of position
- `sort()` – merge sort, n log(n)
- `binarySearch()` – requires ordered sequence
- `shuffle()` – unsort
- `reverse()` – requires ordered sequence
- `rotate()` – of given a distance
- `min()`, `max()` – in a Collection

`sort()` method

- Operates on `List<T>`
  - Require access by index to perform sorting
- Two generic overloads:
  - on `Comparable` objects:

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

  - using a `Comparator` object:

```
<T> void sort(List<T> list,
              Comparator<? super T> cmp)
```

Sort generic

```
T extends Comparable<? super T>
```

MasterStudent Student MasterStudent

- Why `<? super T>` instead of just `<T>` ?
  - Suppose you define
    - `MasterStudent extends Student { }`
  - Intending to inherit the Student ordering
    - It does not implement `Comparable<MasterStudent>`
    - But `MasterStudent` extends (indirectly) `Comparable<Student>`

Custom ordering (alternative)

```
List students = new LinkedList();

students.add(new Student("Mary","Smith",34621));
students.add(new Student("Alice","Knight",13985));
students.add(new Student("Joe","Smith",95635));

Collections.sort(students); // sort by name

Collections.sort(students,
   new StudentIDComparator()); // sort by ID
```

Search

- `<T> int binarySearch(List<? extends Comparable<? super T>> l, T key)`
  - Searches the specified object
  - List must be sorted into ascending order according to natural ordering
- `<T> int binarySearch(List<? extends T> l, T key, Comparator<? super T> c)`
  - Searches the specified object
  - List must be sorted into ascending order according to the specified comparator

Algorithms – Arrays

- Static methods of `java.util.Arrays` class
  - Work on object arrays
- **`sort`**()
- **`binarySearch`**()

Search – Arrays

- `int binarySearch(Object[] a, Object key)`
  - Searches the specified object
  - Array must be sorted into ascending order according to natural ordering
- `int binarySearch(Object[] a, Object key, Comparator c)`
  - Searches the specified object
  - Array must be sorted into ascending order according to the specified comparator

Wrap-up

- The collections framework includes interfaces and classes for containers
- There are two main families
  - Group containers
  - Associative containers
- All the components of the framework are defined as generic types