Java Collection Framework

Version 2 - April 2014

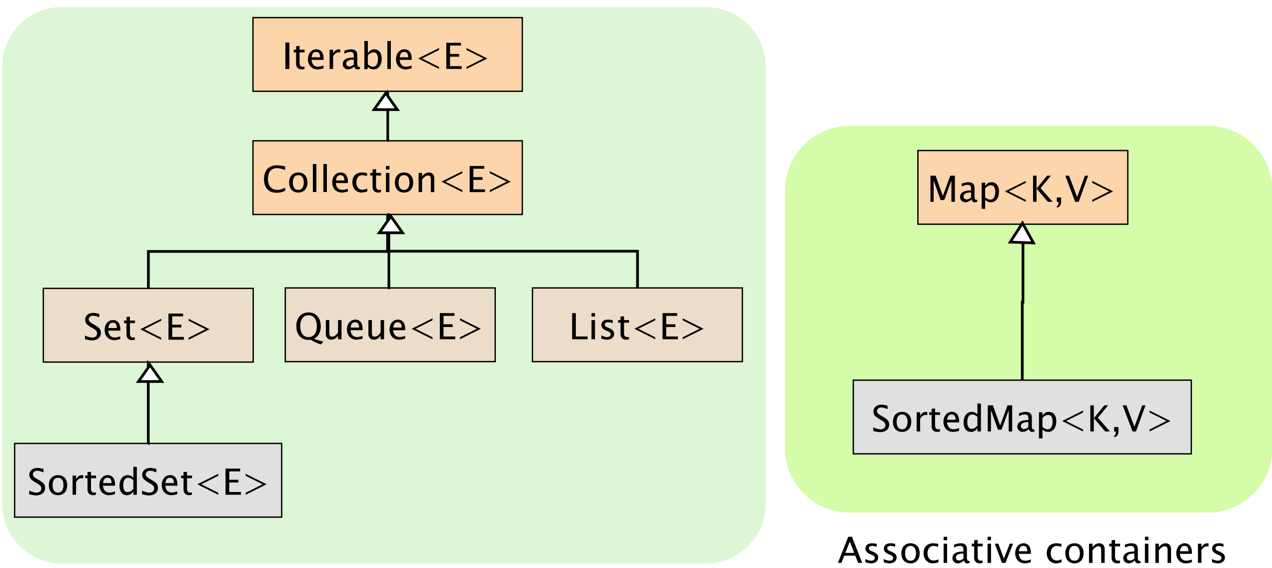
Framework

- Interfaces (ADT, Abstract Data Types)
- Implementations (of ADT)
- Algorithms (sort)

- java.util.*

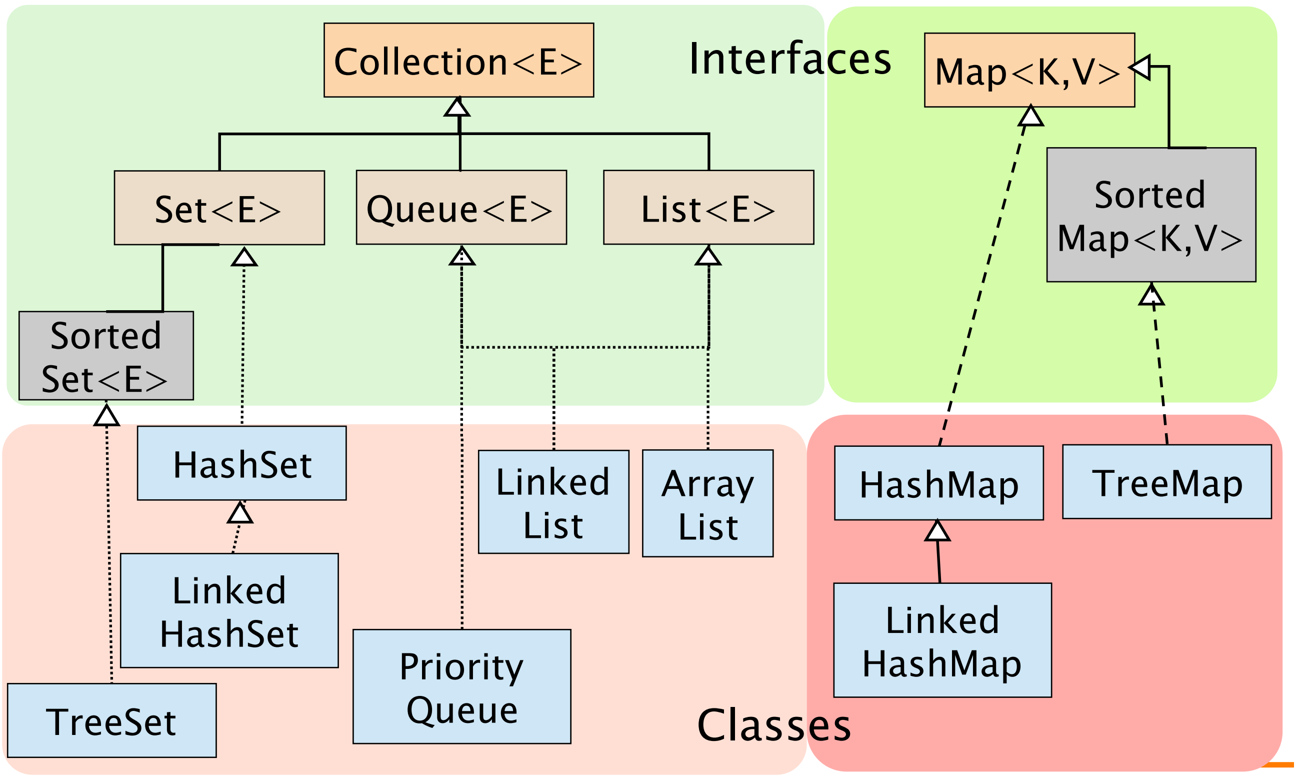
- After Java 5 release
  - Lots of changes about collections

Interfaces



Group containers

Implementations



Internals

data structure

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

interface

classes

Iterable

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

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

  - It returns the iterator on the elements

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

- Is the class the allow 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);
}
```

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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();
    …
}
```

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Collection

- Group of elements (references to objects)
- It is not specified whether they are
  - Ordered / not ordered
  - Duplicated / not duplicated
- Following constructors are 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] );
```


Map

- An object 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<String,Person>();
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();
```

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

Generic list – excerpt

```
public interface List<E>{
   void add(E x);
   Iterator<E> iterator();
}
public interface Iterator<E>{
   E 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();
```

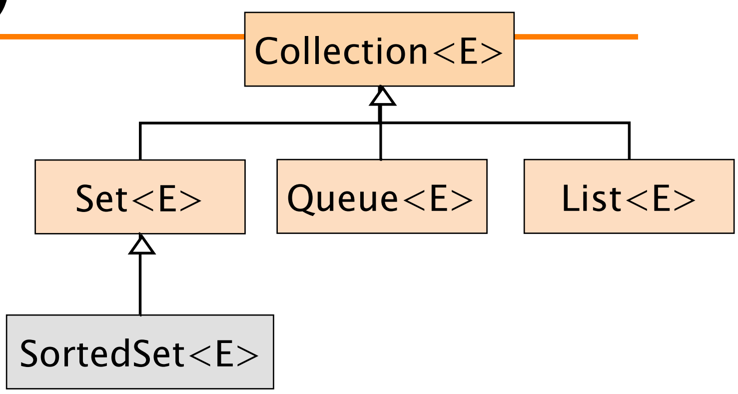
  - With generics (`ArrayList<Integer> list`)

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

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

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


Group containers (Collections)



List

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

List specific methods

```
▪ 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

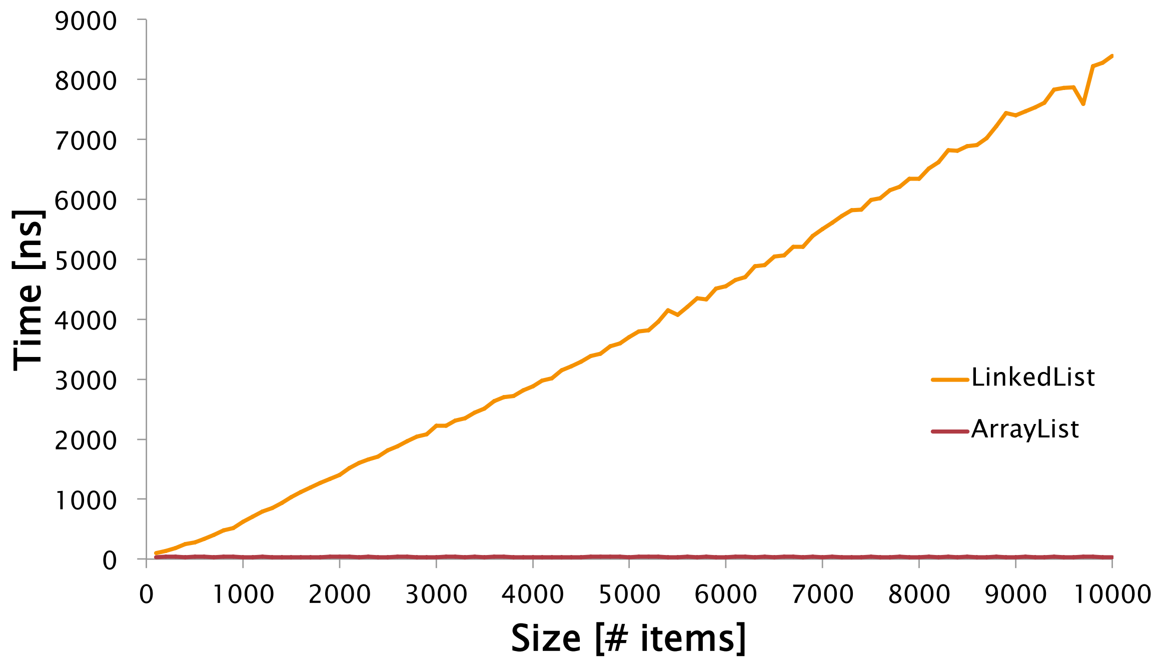
ArrayList

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

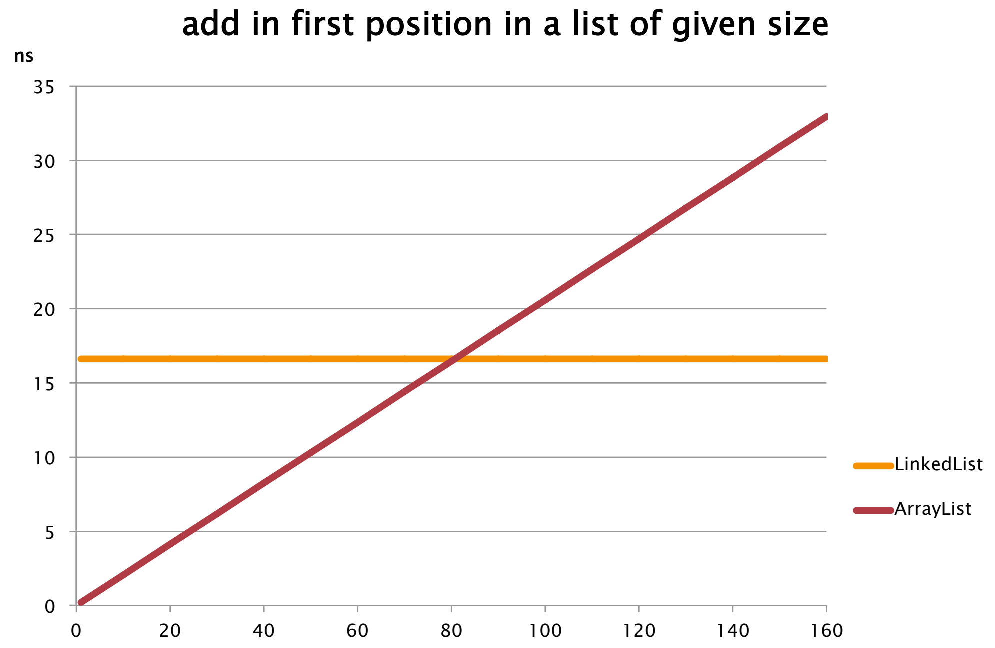
LinkedList

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

List implementations – Get



List Implementations – Add



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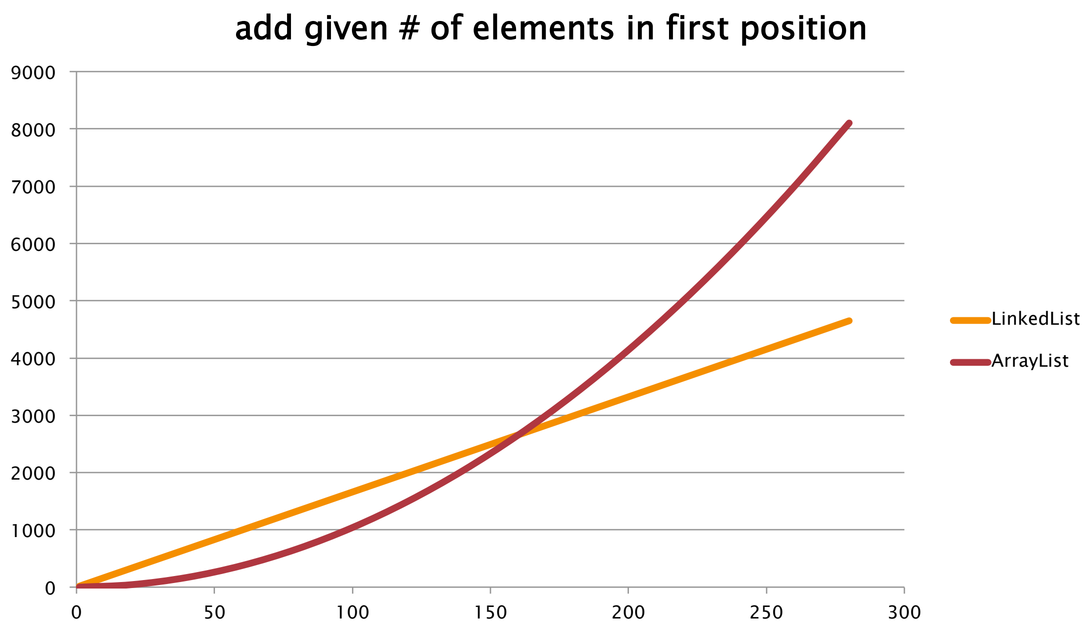
List Implementations – Add



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

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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

- 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

- Contains no methods other than those inherited from Collection
- `add()` has 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

The equals() Contract

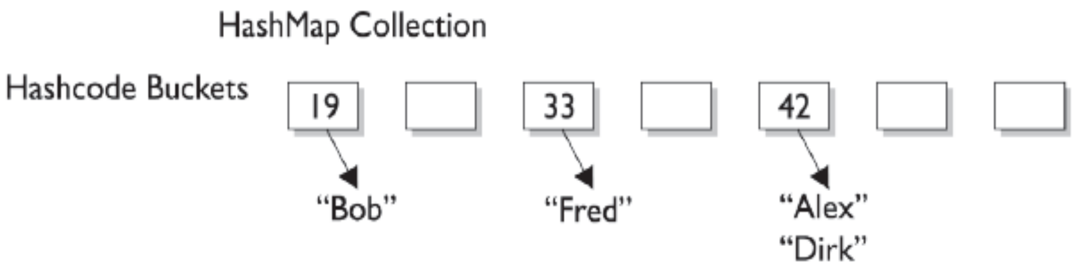
- It is reflexive: x.equals(x) == true
- It is symmetric: x.equals(y) == y.equals(x)
- It is transitive: for any reference values x, y, and z,

  if x.equals(y) == true AND y.equals(z) == true

  => x.equals(z) == true
- It is consistent: for any reference values x and y, multiple invocations of x.equals(y) consistently return true (or false), provided that no information used in equals comparisons on the object is modified.
- x.equals(null) == false

hashCode

Key	Hashcode Algorithm	Hashcode
Alex	A(1) + L(12) + E(5) + X(24)	= 42
Bob	B(2) + O(15) + B(2)	= 19
Dirk	D(4) +I(9) + R(18) + K(11)	= 42
Fred	F(6) + R(18) + E(5) + (D)	= 33



The hashCode() contract

- The hashCode() method must consistently return the same value, if no information used in equals() comparisons on the object is modified.
- If two objects are equal for equals() method, then calling the hashCode() method on the two objects must produce the same integer result.
- If two objects are unequal for equals() method, then calling the hashCode() method on the two objects MAY produce distinct integer results.
  - producing distinct results for unequal objects may improve the performance of hash tables

HashCode()

Condition	Required	Not Required (But Allowed)
x.equals(y) == true	x.hashCode() == y.hashCode()	
x.hashCode() == y.hashCode()		x.equals(y) == true
x.equals(y) == false		No hashCode() requirements
x.hashCode() != y.hashCode()	x.equals(y) == false	

equals() and hashcode()

- equals() and hashCode() are bound together by a joint contract that specifies if two objects are considered equal using the equals() method, then they must have identical hashcode() values.
- To be truly safe:
  - If override equals(), override hashCode()
  - Objects that are equals have to return identical hashcodes.

SortedSet

- 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

Iterators

Note well

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

- Unless you are using the iterator 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

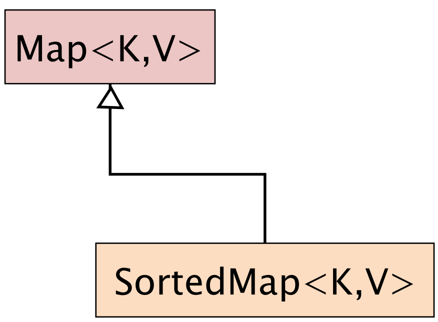
Add (cont' d)

```
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 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()

SortedMap

- 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()){

}
```


Objects Sorting

Comparable interface

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

- Compares the receiving object with the specified object.
- Return value must be:
  - <0 if ***this*** precedes ***obj***
  - ==0 if ***this*** has the same order as ***obj***
  - >0 if ***this*** follows ***obj***

Comparable

- The interface is implemented by language common types in packages **`java.lang`** and **`java.util`**
  - String objects are lexicographically ordered
  - Date objects are chronologically ordered
  - Number and sub-classes are ordered numerically

Custom ordering

- How to define an ordering upon Student objects according to the “natural alphabetic order”

```
public class Student
      implements Comparable<Student>{
   private String first;
   private String last;
   public int compareTo(Student o){
      ...
   }
}
```


Custom ordering

```
public int compareTo(Student o){

  int cmp = lastName.compareTo(s.lastName);

  if(cmp!=0)
    return cmp;
  else
   return firstName.compareTo(s.firstName);
}
```

Ordering “the old way”

- In pre Java 5 code we had:
  - **`public int compareTo(Object obj)`**
- No control on types
- A cast had to be performed within the method
  - Possible ClassCastException when comparing objects of unrelated types

Ordering “the old way”

```
public int compareTo(Object obj){
  Student s = (Student)obj;
  int cmp = lastName.compareTo(s.lastName);
  if(cmp!=0)
    return cmp;
  else
    return firstName.compareTo(s.firstName);
}
```

possible run-time error

Custom ordering (alternative)

```
public interface Comparator<T> {
    public int compare(T o1, T o2);
}
```

- java.util
- Compares its two arguments
- Return value must be
  - <0 if `o1` precedes `o2`
  - ==0 if `o1` has the same ordering as `o2`
  - >0 if `o1` follows `o2`

Custom ordering (alternative)

```
class StudentIDComparator
          implements Comparator<Student> {

  public int compare(Student s1, Student s2){
     return s1.getID() - s2.getID();
  }
}
```

- Usually used to define alternative orderings to Comparable
- The “old way” version compares two Object references

Algorithms

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Algorithms

- Static methods of java.util.Collections class
  - Work on lists

- 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

- Two generic overloads:
  - on Comparable objects:

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

  - using a Comparator object:

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


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()

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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

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