Java Collection Framework

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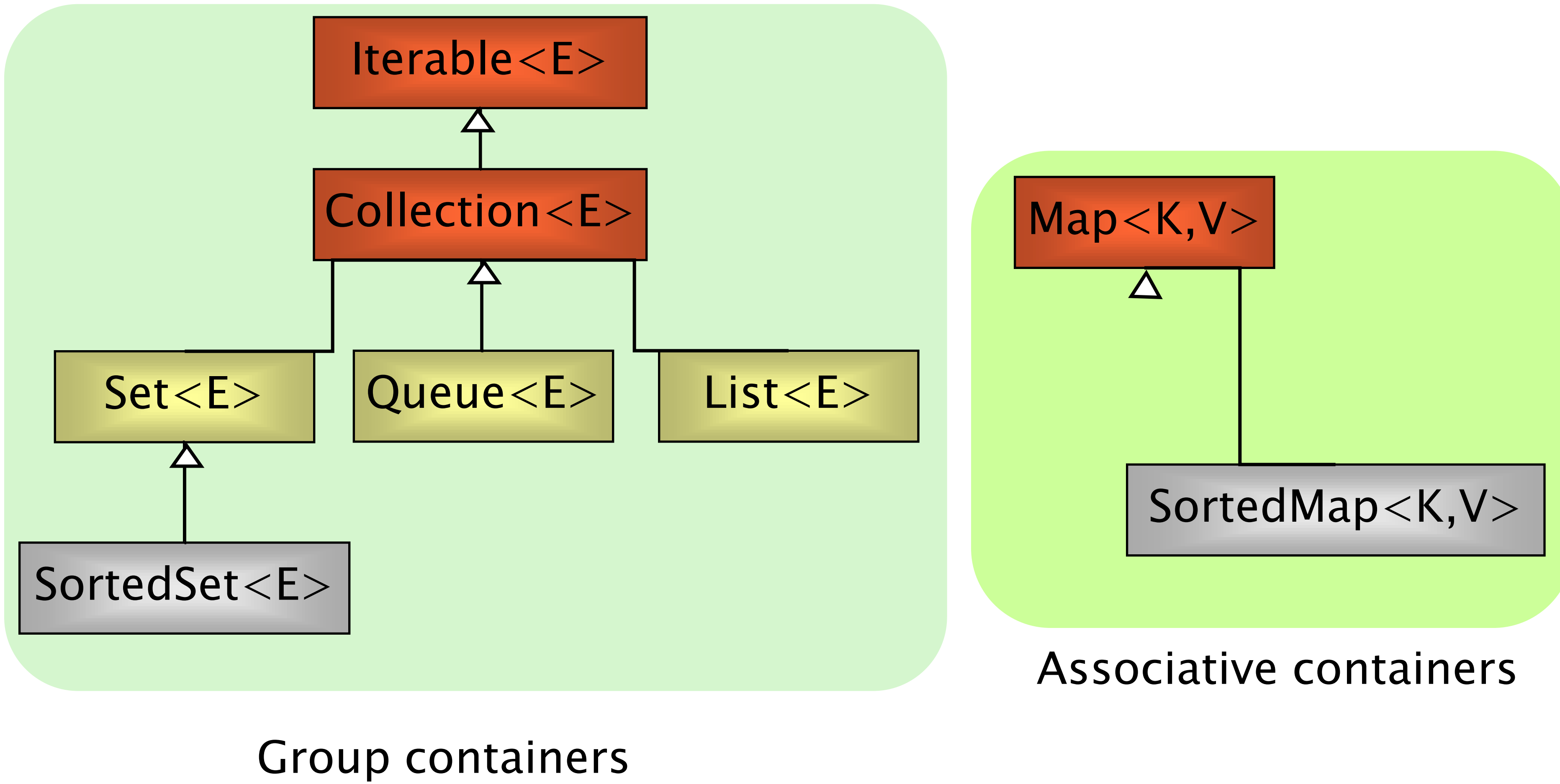
Framework

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

- java.util.*

- Java 5 released!
  - Lots of changes about collections

Interfaces



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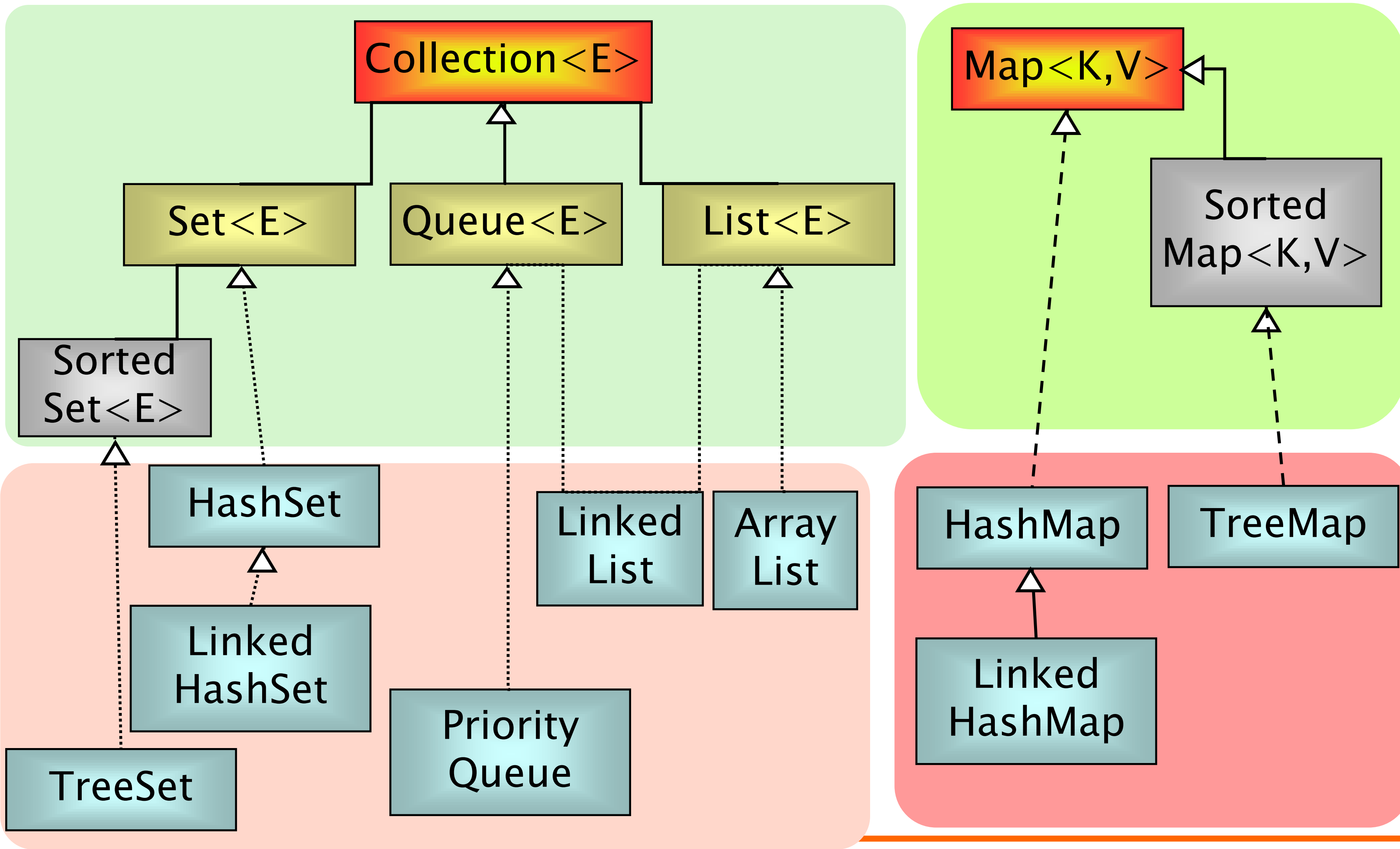
Implementations



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

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
  - T()
  - T(Collection c)

Collection interface

- `int size()`
- `boolean isEmpty()`
- `boolean contains(Object element)`
- `boolean containsAll(Collection c)`
- `boolean add(Object element)`
- `boolean addAll(Collection c)`
- `boolean remove(Object element)`
- `boolean removeAll(Collection c)`
- `void clear()`
- `Object[] toArray()`
- `Iterator 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
  - `T()`
  - `T(Map m)`

Map interface

- `Object put(Object key, Object value)`
- `Object get(Object key)`
- `Object remove(Object key)`
- `boolean containsKey(Object key)`
- `boolean containsValue(Object value)`
- `public Set keySet()`
- `public Collection 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

- From Java 5, all collection interfaces and classes have been redefined as Generics
- Use of generics lead 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();
```

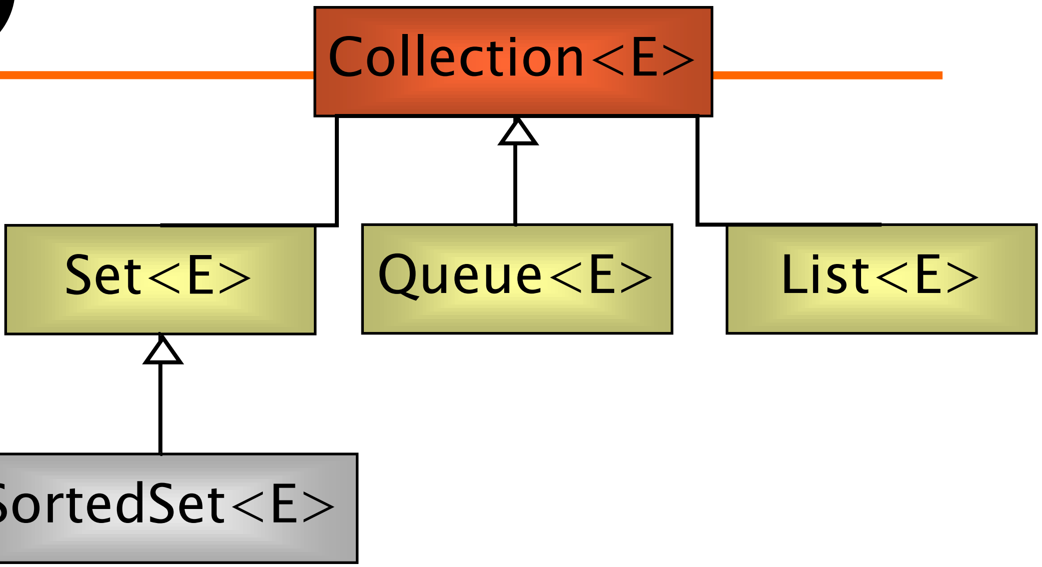
  - With generics (`ArrayList<Integer> list`)

```
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 additional methods

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

- `boolean addAll(int index, Collection c)`
- `int indexOf(Object o)`
- `int lastIndexOf(Object o)`
- `List subList(int fromIndex, int toIndex)`

List implementations

ArrayList

- get(n)
  - Constant time
- Insert (beginning) and delete while iterating
  - Linear

LinkedList

- get(n)
  - Linear time
- Insert (beginning) and delete while iterating
  - Constant

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()`

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
```

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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
```

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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,

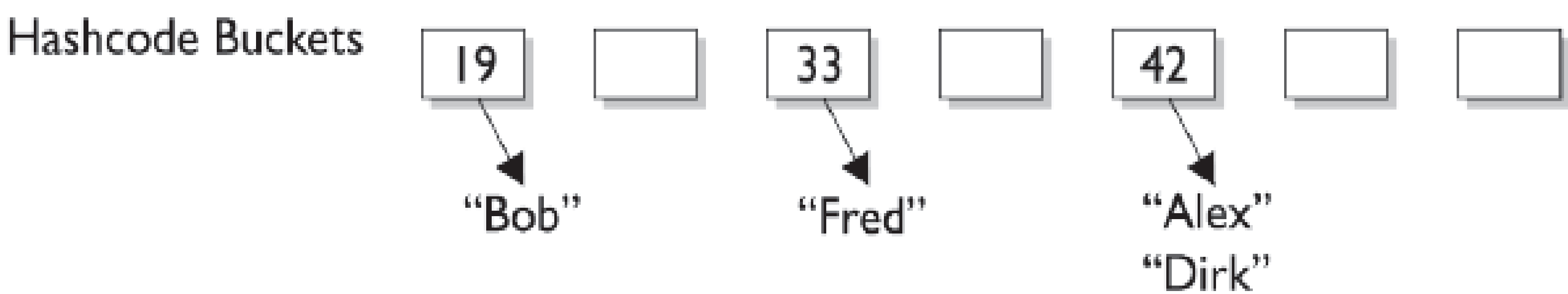
  if x.equals(y) == true AND y.equals(z) == true

  => 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

HashMap Collection



The hashCode() contract

- The hashCode() method must consistently return the same int, 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 int results for unequal objects may improve the performance of hashtables

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

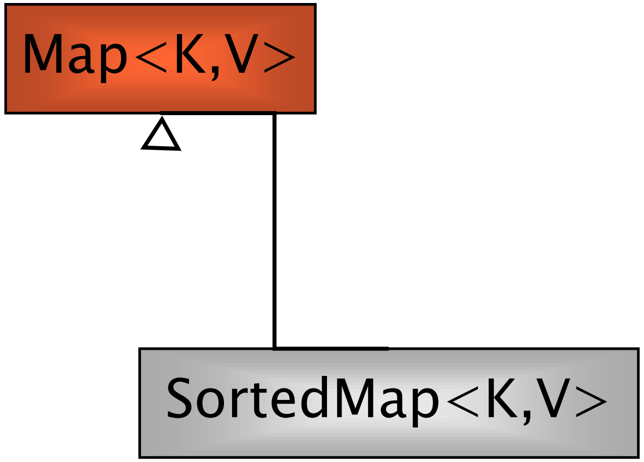
- HashSet implements Set
  - Hash tables as internal data structure (faster)
- LinkedHashSet extends HashSet
  - Elements are traversed by iterator according to the insertion order

- 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

Associative containers (Maps)



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 of Set
- HashMap implements Map
  - No order
- LinkedHashMap extends HashMap
  - Insertion order
- TreeMap implements SortedMap
  - Ascending key order

HashMap

- Get/set 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()){

}
```

Iterators

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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 interface

- `boolean hasNext()`
- `Object next()`
- `void remove()`

Iterator examples

Print all objects in a list

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

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Iterator examples

The for-each syntax avoids using iterator directly

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

Iteration examples

Print all values in a map
(variant using while)

```
Map<String,Person> people =
            new HashMap<String,Person>();
…
Collection<Person> values = people.values();

for(Person p: values) {
   System.out.println(p);
}
```

Iteration examples

Print all keys AND values in a map

```
Map<String,Person> people =
              new HashMap<String,Person>();
…
Collection<String> keys = people.keySet();
for(String ssn: keys) {
   Person p = people.get(ssn);
   System.out.println(ssn + " - " + 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();
    …
}
```

Iteration examples (until Java 1.4)

Print all values in a map (variant using while)

```
Map people = new HashMap();
…
Collection values = people.values();
Iterator i = values.iterator();
while( i.hasNext() ) {
    Person p = (Person)i.next();
    …
}
```

Iteration examples (until Java 1.4)

Print all keys AND values in a map

```
Map people = new HashMap();
…
Collection keys = people.keySet();
for(Iterator i= keys.iterator(); i.hasNext();) {
    String ssn = (String)i.next();
    Person p = (Person)people.get(ssn);
    …
}
```

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()`

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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

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Objects Ordering

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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

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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`

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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>`

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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