Generics, Collections, & Iterators

Lecture 5 (23 february 2021)

Introduction to Java Programming (Liang): chapters 19, 20, & 21

Radboud University

GENERICS

software development

goal

- correct, robust, adaptable and extendable
- fast development, reuse existing parts/libraries

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OO tools/principles

- **encapsulation**: information hiding
- **realization**: implements
- **composition**: has-a
- **inheritance**: is-a, extends
- **polymorphism**: overriding

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Java additions

- **strong static typing**: spot all type problems at compile time

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Java additions

- **strong static typing**: spot all type problems at compile time
- **exception mechanism** to handle runtime errors
- **generics**: increase reusability and type safety by type parameters

the design of `equals`

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desirable property: **symmetry**

- `x.equals(y)` ⇔ `y.equals(x)`

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`false` if there is no object or it has another type

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the design of `equals`

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public class Person {
  protected String name;
  public Person(String name) {
    this.name = name;
  }
  @Override
  public boolean equals(Object obj) {
    if (obj == null || getClass() != obj.getClass()) {
      return false;
    }
    final Person q = (Person) obj;
    return name.equals(q.name);
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```java
public class Student extends Person {
  protected int num;
  public Student(int num, String name) {
    super(name);
    this.num = num;
  }
  @Override
  public boolean equals(Object obj) {
    if (obj == null || getClass() != obj.getClass()) {
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or some other choice

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```

```
private void run() {
  Person  p = new Person("Alice");
  Student s = new Student(7, "Alice");
  System.out.println("p.equals(s) = " + p.equals(s));
  System.out.println("s.equals(p) = " + s.equals(p));
}
```

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    final Student other = (Student) obj;
    return this.num == other.num;
  }
}
```

or some other choice

```
p.equals(s) = false
s.equals(p) = false
```

the design of equals

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  }
  @Override
  public boolean equals(Object obj) {
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  System.out.println("p.equals(s) = " + p.equals(s));
  System.out.println("s.equals(p) = " + s.equals(p));
}
```

```
p.equals(s) = false
s.equals(p) = false
```

(Person) Student s would be equal to p

the design of `equals`: inheritance safe

```
public class Person {
  protected String name;
  public Person(String name) {
    this.name = name;
  }
  @Override
  public boolean equals(Object obj) {
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}
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```
p.equals(s) = true
s.equals(p) = false
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the design of equals: inheritance safe

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violates x.equals(y) ⇔ y.equals(x)

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might still be a good design choice

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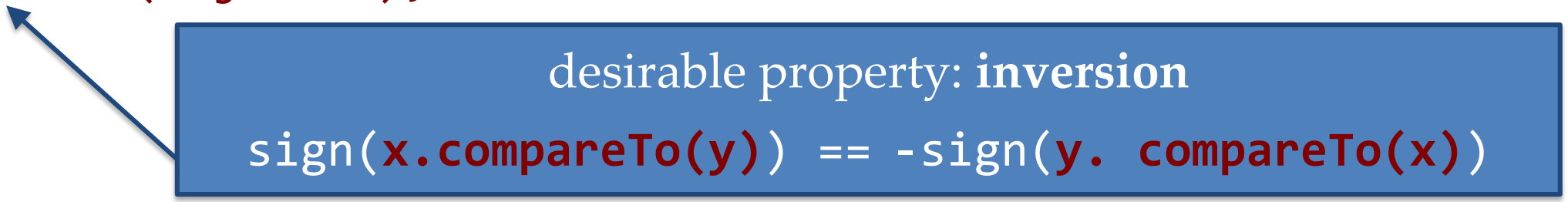

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desirable property: **inversion**

`sign(x.compareTo(y)) == -sign(y. compareTo(x))`

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2) throw an exception

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  int compareTo(Object o);
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```

Note: this is not the definition of Comparable in the standard Java API

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a type-safe compare

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interface Comparable<T> {
  int compareTo(T o);
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```

a type-safe compare

generic type argument:
"formal generic type"

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```

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generic type argument: "formal generic type"

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generic instantiation: "actual concrete type"

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```

typing: o is Person

```
public class Student extends Person {
  ..
  @Override
  int compareTo(Student s) {
    return num - s.num;
  }
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```

a type-safe compare

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private void run() {
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  System.out.println("s.compareTo(p) = " + s.compareTo(p));
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```

```
p.compareTo(s) = 0
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s.compareTo(p) = 0
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p.compareTo(s) = 0
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why?

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  int compareTo(T o);
}
```

implements Comparable<Student> not allowed

"actual concrete type"

```
public class Person implements Comparable<Person> {
  ..
  @Override
  public int compareTo(Person o) {
    return name.compareTo(o.name);
  }
}
```

typing: o is Person

```
public class Student extends Person {
  ..
  @Override
  int compareTo(Student s) {
    return num - s.num;
  }
}
```

```
private void run() {
  Person  p = new Person("Alice");
  Student s = new Student(7, "Alice");
  System.out.println("p.compareTo(s) = " + p.compareTo(s));
  System.out.println("s.compareTo(p) = " + s.compareTo(p));
}
```

```
p.compareTo(s) = 0
s.compareTo(p) = 0
```

why?

a type-safe compare

generic type argument:
"formal generic type"

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

implements Comparable<Student> not allowed

"actual concrete type"

```
public class Person implements Comparable<Person> {
  ..
  @Override
  public int compareTo(Person o) {
```

```
public class Student extends Person {
  ..
  @Override
  int compareTo(Student s) {
```

Compile-time error:
"method does not override or implement a method from a supertype"

```
private void run() {
  Person  p = new Person("Alice");
  Student s = new Student(7, "Alice");
  System.out.println("p.compareTo(s) = " + p.compareTo(s));
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}
```

```
p.compareTo(s) = 0
s.compareTo(p) = 0
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why?

a type-safe compare

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

```
public class Person implements Comparable<Person> {
  ..
  @Override
  public int compareTo(Person o) {
    return name.compareTo(o.name);
  }
}
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```
public class Student extends Person {
  ..
  @Override
  int compareTo(Person s) {
    return num - s.num;
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```

a type-safe compare

```
interface Comparable<T> {
  int compareTo(T o);
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public class Person implements Comparable<Person> {
  ..
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  }
}
```

```
public class Student extends Person {
  ..
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```

a type-safe compare

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

```
public class Person implements Comparable<Person> {
  ..
  @Override
  public int compareTo(Person o) {
    return name.compareTo(o.name);
  }
}
```

```
public class Student extends Person {
  ..
  @Override
  int compareTo(Person s) {
    return num - s.num;
  }
}
```

Compile-time error:
"error: cannot find symbol
return this.num - s.num;
symbol: variable snum
location: variable s of type **Person**"

equals with different types

```
public class Person implements Comparable<Person> {
  ..
  public boolean equals(Object obj) {
    if (obj == null || getClass() != obj.getClass()) {
      return false;
    }
    final Person q = (Person) obj;
    return name.equals(q.name);
  }

  public int compareTo(Person o) {
    return name.compareTo(o.name);
  }
}
```

```
Person p = new Person("Alice");
p.equals("Alice");
a) type error
b) true
c) false
```

equals with different types

```
public class Person implements Comparable<Person> {
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  public int compareTo(Person o) {
    return name.compareTo(o.name);
  }
}
```

```
Person p = new Person("Alice");
p.compareTo("Alice");
a) type error
b) 0
c) ≠ 0
```

compareTo with different types

```
public class Person implements Comparable<Person> {
  ..
  public boolean equals(Object obj) {
    if (obj == null || getClass() != obj.getClass()) {
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    return name.equals(q.name);
  }

  public int compareTo(Person o) {
    return name.compareTo(o.name);
  }
}
```

```
Person p = new Person("Alice");
p.compareTo("Alice");
a) type error
b) 0
c) ≠ 0
```

equals with null

```
public class Person implements Comparable<Person> {
  ..
  public boolean equals(Object obj) {
    if (obj == null || getClass() != obj.getClass()) {
      return false;
    }
    final Person q = (Person) obj;
    return name.equals(q.name);
  }

  public int compareTo(Person o) {
    return name.compareTo(o.name);
  }
}
```

```
Person p = new Person("Alice");
p.equals(null);
a) type error
b) exception
c) true
d) false
```

equals with null

```
public class Person implements Comparable<Person> {
  ..
  public boolean equals(Object obj) {
    if (obj == null || getClass() != obj.getClass()) {
      return false;
    }
    final Person q = (Person) obj;
    return name.equals(q.name);
  }

  public int compareTo(Person o) {
    return name.compareTo(o.name);
  }
}
```

```
Person p = new Person("Alice");
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d) false
```

compareTo with null

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public class Person implements Comparable<Person> {
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    if (obj == null || getClass() != obj.getClass()) {
      return false;
    }
    final Person q = (Person) obj;
    return name.equals(q.name);
  }

  public int compareTo(Person o) {
    return name.compareTo(o.name);
  }
}
```

```
Person p = new Person("Alice");
p.compareTo(null);
a) type error
b) exception
c) 0
d) ≠ 0
```

compareTo with null

```
public class Person implements Comparable<Person> {
  ..
  public boolean equals(Object obj) {
    if (obj == null || getClass() != obj.getClass()) {
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    }
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```

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Person p = new Person("Alice");
p.compareTo(null);
a) type error
b) exception
c) 0
d) ≠ 0
```

more uses of generic types: counting word frequency

store word and its count in array of pairs

1. update array for each word in input
2. sort array (lexicographically)
3. show array

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store word and its count in array of pairs

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```
To be or not to be - that is the question!
```

more uses of generic types: counting word frequency

store word and its count in array of pairs

1. update array for each word in input
2. sort array (lexicographically)
3. show array

```
To be or not to be - that is the question!
```

```
Words:
be 2
is 1
not 1
or 1
question 1
that 1
the 1
to 2
```

make this map of words to count more reusable

many programs need pairs

- often other types than `String` and `int`

make this map of words to count more reusable

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- using `Object` instead of `String` and `int` spoils type safety

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many programs need a `Map`

- not restricted to `Map` from `String` to `int`
  - `String` to `double` in expressions
  - `StudentNumber` to `Student`
  - `Zipcode` to `Address`
  - ..

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in Java we can make this more reusable by introducing type variables:
generic programming

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in Java we can make this more reusable by introducing type variables:
generic programming

- available since 2004 in JSE 5.0, SDK 1.5

reusable Pair

```
public class Pair <K, V> {
  private K key;
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K and V are generic type variables
typically a single uppercase letter

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K and V are used like a type: attribute

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public class Pair <K, V> {
  private K key;
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    this.key = key;
    this.val = val;
  }
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K and V are generic type variables
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public class Pair <K, V> {
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  public Pair(K key, V val) {
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    this.val = val;
  }

  public K getKey() { return key; }
  public V getVal() { return val; }
  public void setVal(V val) { this.val = val; }
}
```

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K and V are generic type variables typically a single uppercase letter

K and V are used like a type: attribute

K and V are used like a type: argument of method

K and V are used like a type: result of method

allowed instances of type variable: any reference type

this **excludes** the **primitive types**

```
Pair<int, Student> p3 = new Pair<>(42, alice);
```

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this is **NOT** allowed !

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solution: use **wrapper types**

- these are predefined in Java:

  `int`, `double`, `char`, `boolean` wrapped in
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use this as

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Pair<Integer, Student> p3 = new Pair<>(42, alice);
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autoboxing / auto-unboxing: automatic conversion between primitive & wrapper

```
Integer box = 7;
int plain   = box;
```

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Pair<Integer, Student> p3 = new Pair<>(42, alice);
```

autoboxing / auto-unboxing: automatic c…er

```
Integer box = 7;
int plain   = box;
```

instead of

```
Integer box = new Integer(7);
int plain   = box.intValue();
```

mapping words to count – 1 / 2

```
public class Map {
  private Pair <String, Integer> [] map;
  protected int count = 0;

  public Map(int size) {
    map = new Pair[size];
  }
```

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public class Map {
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  public Map(int size) {
    map = new Pair[size];
  }

  public void add(String key) {
    for (Pair <String, Integer> pair : map) {
      if (pair != null && pair.getKey().equals(key)) {
        pair.setVal( pair.getVal() + 1 );
        return;
      }
    }
    map[count++] = new Pair<>(key, 1);
  }
```

mapping words to count – 1 / 2

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```

actual types

diamond operator: deduced type
compiler must be able to deduce at compile-time

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      }
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```

note: creating an **Array of** Pairs

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      if (pair != null && pair.getKey().equals(key)) {
        pair.setVal( pair.getVal() + 1 );
        return;
      }
    }
    map[count++] = new Pair<>(key, 1);
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```

note: creating an **Array of** Pairs

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note: creating an **Array of** Pairs

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note: creating a **Pair**

ignoring size problems

mapping words to count – 1 / 2

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  }

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    for (Pair <String, Integer> pair : map) {
      if (pair != null && pair.getKey().equals(key)) {
        pair.setVal(pair.getVal() + 1 );
        return;
      }
    }
    map[count++] = new Pair<>(key, 1);
  }
```

note: creating an **Array of** Pairs

actual types

no diamond operator here ! ?

postfix ++ returns the value *before* increment

diamond operator: deduced type
compiler must be able to deduce at compile-time!

note: creating a **Pair**

ignoring size problems

mapping words to count – 2 / 2

```
public int get(String key) {
    for (Pair<String, Integer> pair : map) {
      if (pair != null && pair.getKey().equals(key)) {
        return pair.getVal();
      }
    }
    return 0;
  }
```

```
}
```

mapping words to count – 2 / 2

```
 public int get(String key) {
    for (Pair<String, Integer> pair : map) {
      if (pair != null && pair.getKey().equals(key)) {
        return pair.getVal();
      }
    }
    return 0;
  }

  public String [] keys () {
    String [] keys = new String[count];
    for (int i = 0; i < count; i += 1) {
      keys[i] = map[i].getKey();
    }
    Arrays.sort(keys);
    return keys;
  }
}
```

counting words

```
private void run() {
  Scanner scan = new Scanner(line).useDelimiter("\\W+");
  Map map = new Map(100);
  while (scan.hasNext()) {
    map.add( scan.next().toLowerCase() );
  }
  for (String key: map.keys()) {
    System.out.println(key + ": " + map.get(key));
  }
}
```

counting

one or more “non-word characters”

```
private void run() {
  Scanner scan = new Scanner(line).useDelimiter("\\W+");
  Map map = new Map(100);
  while (scan.hasNext()) {
    map.add( scan.next().toLowerCase() );
  }
  for (String key: map.keys()) {
    System.out.println(key + ": " + map.get(key));
  }
}
```

counting

one or more “non-word characters”

```
private void run() {
  Scanner scan = new Scanner(line).useDelimiter("\\W+");
  Map map = new Map(100);
  while (scan.hasNext()) {
    map.add( scan.next().toLowerCase() );
  }
  for (String key: map.keys()) {
    System.out.println(key + ": " + map.get(key));
  }
}
```

```
be: 2
is: 1
not: 1
or: 1
question: 1
that: 1
the: 1
to: 2
```

generics for a single method

often the generic variables belong to a class;

they can also belong to a single method

```
public <K,V> Pair<V,K> swap (Pair<K,V> p) {
  return new Pair<>(p.getVal(), p.getKey());
}
```

generics for a single method

often the generic variables belong to a class;

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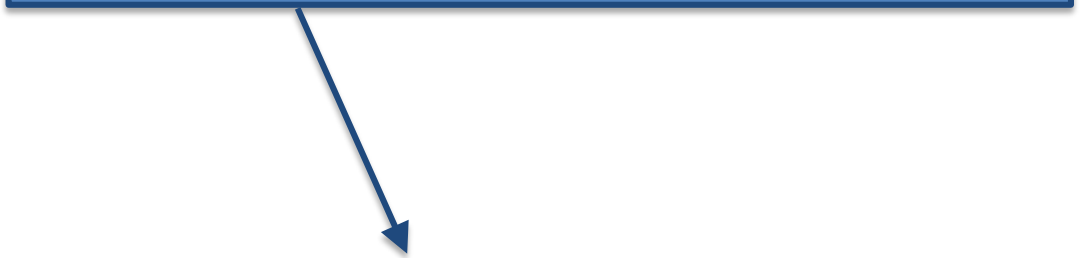
generic type arguments for method



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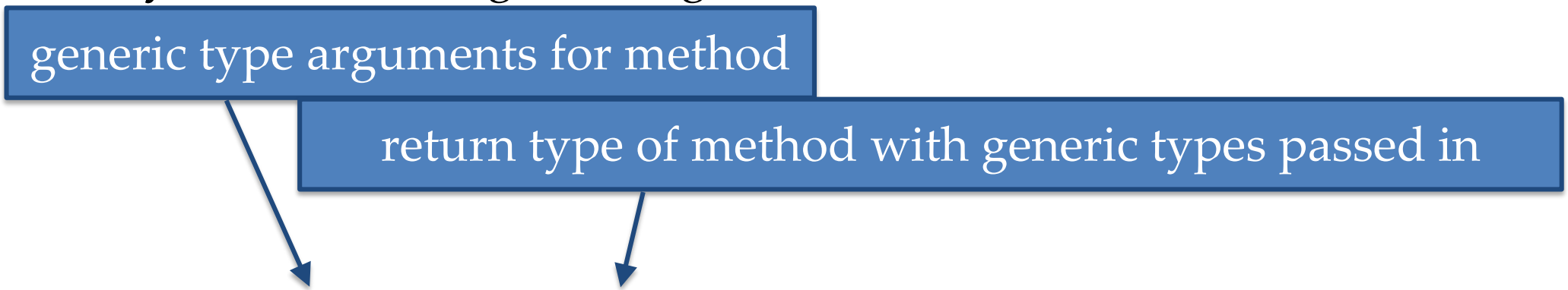


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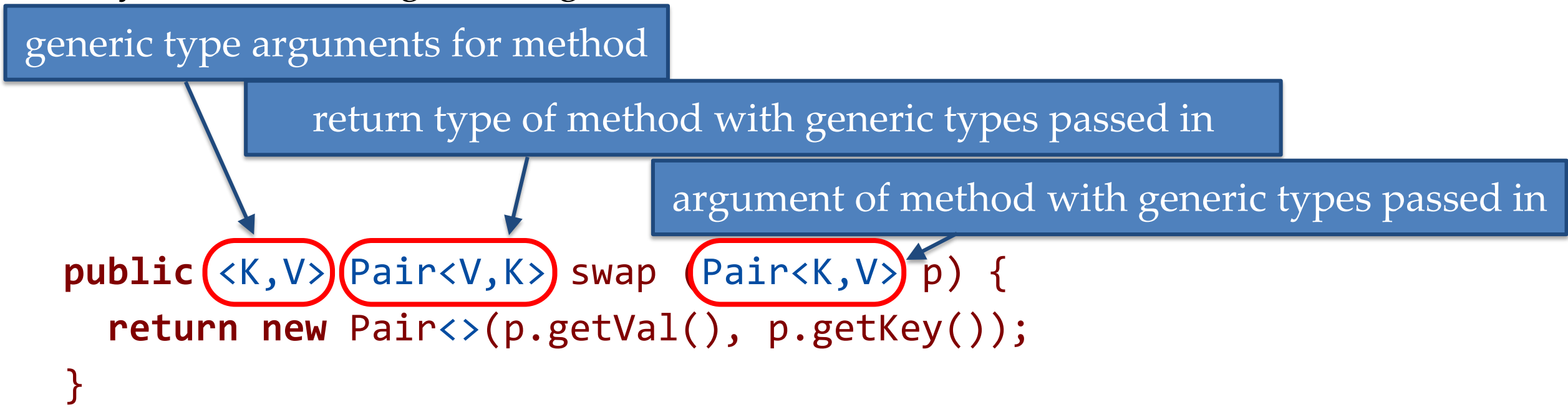

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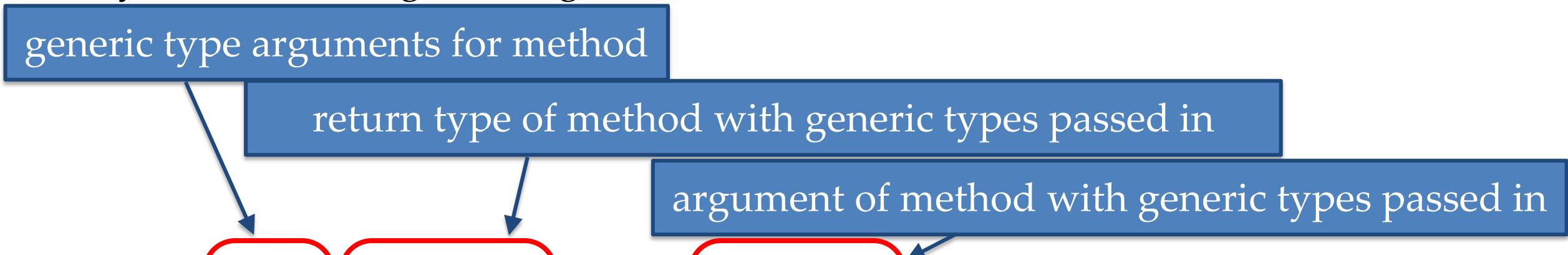



```
public <K,V> Pair<V,K> swap ( Pair<K,V> p) {
  return new Pair<>(p.getVal(), p.getKey());
}
```

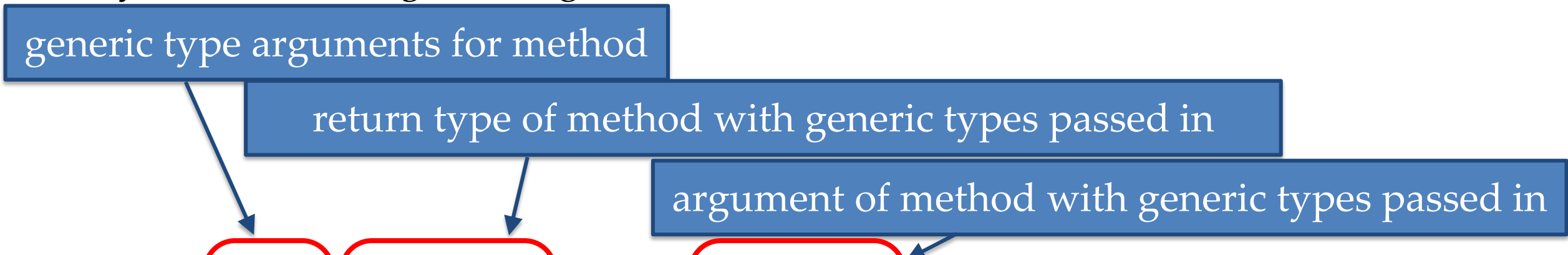
use this like any other method:

```
System.out.println(this.swap( pair ));
```

generics for a single method

often the generic variables belong to a class;

they can also belong to a single method




```
public <K,V> Pair<V,K> swap ( Pair<K,V> p) {
  return new Pair<>(p.getVal(), p.getKey());
}
```

use this like any other method:

```
System.out.println(this.swap( pair ));
```

or pass the type explicitly:

```
System.out.println(this.<String, Integer>swap( pair ));
```

type erasure

The one big limitation of Java generics:

type erasure

The one big limitation of Java generics:

generic types are checked at **compile-time**,

type erasure

The one big limitation of Java generics:

generic types are checked at **compile-time**,

generic type information is **then removed**

type erasure

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```
GenPair<Integer, String>
```

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```
GenPair<Integer, String> → GenPair
```

type erasure

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```
GenPair<Integer, String> → GenPair
                           T getX()
```

type erasure

The one big limitation of Java generics:

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```
GenPair<Integer, String> → GenPair
T getX() → Object getX()
```

type erasure

The one big limitation of Java generics:

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generic type information is **then removed**

```
GenPair<Integer, String> → GenPair
T getX() → Object getX()
void setX(T x)
```

type erasure

The one big limitation of Java generics:

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generic type information is **then removed**

```
GenPair<Integer, String> → GenPair
                T getX() → Object getX()
          void setX(T x) → void setX(Object x)
```

type erasure

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```
GenPair<Integer, String> → GenPair
T getX() → Object getX()
void setX(T x) → void setX(Object x)
ArrayList<String> list = new ArrayList<>();
```

type erasure

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generic type information is **then removed**

```
GenPair<Integer, String> → GenPair
T getX() → Object getX()
void setX(T x) → void setX(Object x)
ArrayList<String> list = new ArrayList<>(); → ArrayList list = new ArrayList();
```

type erasure

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```
GenPair<Integer, String> → GenPair
T getX() → Object getX()
void setX(T x) → void setX(Object x)
ArrayList<String> list = new ArrayList<>(); → ArrayList list = new ArrayList();
String s = list.get(0);
```

type erasure

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```
GenPair<Integer, String> → GenPair
T getX() → Object getX()
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String s = list.get(0); → String s = (String)(list.get(0));
```

type erasure

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T getX() → Object getX()
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ArrayList<String> list = new ArrayList<>(); → ArrayList list = new ArrayList();
String s = list.get(0); → String s = (String)(list.get(0));
<E extends Comparable> int e(E o1, E o2)...
```

type erasure

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generic type information is **then removed**

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GenPair<Integer, String> → GenPair
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String s = list.get(0); → String s = (String)(list.get(0));
<E extends Comparable> int e(E o1, E o2)... → int e(Comparable o1,
                                                    Comparable o2) ...
```

type erasure

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                                                    Comparable o2) ...
```

conclusion: the **JVM** has **no knowledge** of the generic type information

type erasure

The one big limitation of Java generics:

generic types are checked at **compile-time**,

generic type information is **then removed**

```
GenPair<Integer, String> → GenPair
                T getX() → Object getX()
           void setX(T x) → void setX(Object x)
ArrayList<String> list = new ArrayList<>(); → ArrayList list = new ArrayList();
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conclusion: the **JVM** has **no knowledge** of the generic type information

at runtime there is no difference between
`GenPair<Integer, String>` and `GenPair<String, Integer>`:

type erasure

The one big limitation of Java generics:

generic types are checked at **compile-time**,

generic type information is **then removed**

```
GenPair<Integer, String> → GenPair
T getX() → Object getX()
void setX(T x) → void setX(Object x)
ArrayList<String> list = new ArrayList<>(); → ArrayList list = new ArrayList();
String s = list.get(0); → String s = (String)(list.get(0));
<E extends Comparable> int e(E o1, E o2)... → int e(Comparable o1,
                                                    Comparable o2) ...
```

conclusion: the **JVM** has **no knowledge** of the generic type information

at runtime there is no difference between `GenPair<Integer, String>` and `GenPair<String, Integer>`:

- both have type `GenPair`!

limitation of generic arguments

type parameter `<T>` cannot be used as a constructor (to create a new objects)

```
T object  = new T();
T[] array = new T[10];
```

limitation of generic arguments

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this is **NOT** allowed !

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this is **NOT** allowed !

no generic type parameters of a Class in static methods

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no generic type parameters of a Class in static methods

- (caveat: generic static methods that take generic type arguments are okay, e.g.
  `public static <K> void add (K o) { … } `)

limitation of generic arguments

type parameter `<T>` cannot be used as a constructor (to create a new objects)

```
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T[] array = new T[10];
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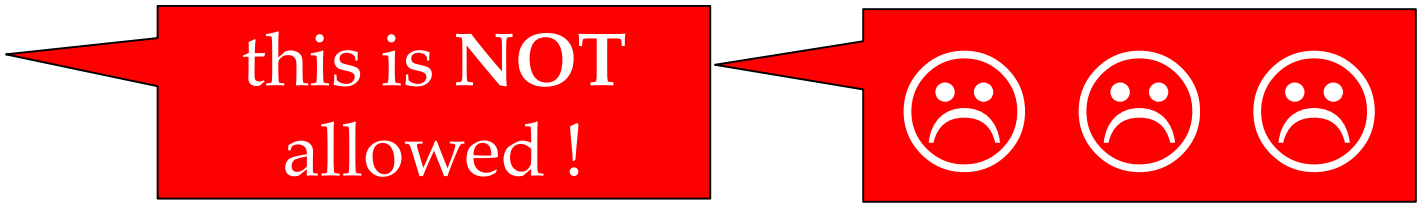

no generic type parameters of a Class in static methods

- (caveat: generic static methods that take generic type arguments are okay, e.g. `public static <K> void add (K o) { … } `)

no generic exceptions

a generic map 1 / 2

```
public class MapGen <K extends Comparable<K>, V> {
  private Pair <K, V> [] map;
  private int count = 0;

  public MapGen(int size) {
    map = new Pair[size];    ☹
  }
```

a generic map 1 / 2

```
public class MapGen <K extends Comparable<K>, V> {
  private Pair <K, V> [] map;
  private int count = 0;

  public MapGen(int size) {
    map = new Pair[size];     ☹
  }
```

bounded generic type:
to ensure that we can sort the pairs

a generic map 1 / 2

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public class MapGen <K extends Comparable<K>, V> {
  private Pair <K, V> [] map;
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  }
```

☹

bounded generic type:
to ensure that we can sort the pairs

`new Pair<>[size]` not allowed

a generic map 1 / 2

```
public class MapGen <K extends Comparable<K>, V> {
  private Pair <K, V> [] map;
  private int count = 0;

  public MapGen(int size) {
    map = new Pair[size];    ☹
  }

  public void add(K key, V val) {
    for (Pair<K, V> pair : map) {
      if (pair != null && pair.getKey().equals(key)) {
        pair.setVal(val);
        return;
      }
    }
    map[count++] = new Pair<>(key, val);
  }
```

bounded generic type:
to ensure that we can sort the pairs

`new Pair<>[size]` not allowed

a generic map 2 / 2

```
  public V get(K key) {
    for (Pair<K, V> pair : map) {
      if (pair != null && pair.getKey().equals(key)) {
        return pair.getVal();
      }
    }
    return null;
  }









}
```

a generic map 2 / 2

```
  public V get(K key) {
    for (Pair<K, V> pair : map) {
      if (pair != null && pair.getKey().equals(key)) {
        return pair.getVal();
      }
    }
    return null;
  }

  public K [] keys () {
    K [] keys = (K[]) new Object[count];
    for (int i = 0; i < count; i += 1) {
      keys[i] = map[i].getKey();
    }
    Arrays.sort(keys);
    return keys;
  }
}
```

a generic map 2 / 2

```
  public V get(K key) {
    for (Pair<K, V> pair : map) {
      if (pair != null && pair.getKey().equals(key)) {
        return pair.getVal();
      }
    }
    return null;
  }

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    for (int i = 0; i < count; i += 1) {
      keys[i] = map[i].getKey();
    }
    Arrays.sort(keys);
    return keys;
  }
}
```

since `new K [count]` is not allowed

a generic map 2 / 2

```
  public V get(K key) {
    for (Pair<K, V> pair : map) {
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      }
    }
    return null;
  }

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    for (int i = 0; i < count; i += 1) {
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    }
    Arrays.sort(keys);
    return keys;
  }
}
```

since `new K [count]` is not allowed

this gives an exception:
cannot cast `Object` to `Comparable`

a generic map 2 / 2

```
  public V get(K key) {
    for (Pair<K, V> pair : map) {
      if (pair != null && pair.getKey().equals(key)) {
        return pair.getVal();
      }
    }
    return null;
  }

  public K [] keys () {
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      keys[i] = map[i].getKey();
    }
    Arrays.sort(keys);
    return keys;
  }
}
```

since `new K [count]` is not allowed

this gives an exception:
cannot cast `Object` to `Comparable`

disappointing that the compiler does not spot this

fixing the generic map

return an `ArrayList<K>` instead of an `Array`

```
public ArrayList<K> keys () {
  ArrayList<K> keys = new ArrayList<>(count);
  for (int i = 0; i < count; i += 1) {
    keys.add( map[i].getKey() );
  }
  Collections.sort(keys);
  return keys;
}
```

fixing the generic map

return an `ArrayList<K>` instead of an `Array`

```
public ArrayList<K> keys () {
  ArrayList<K> keys = new ArrayList<>(count);
  for (int i = 0; i < count; i += 1) {
    keys.add( map[i].getKey() );
  }
  Collections.sort(keys);
  return keys;
}
```

we can always add an element to an `ArrayList`,
this is a much better solution too for `private Pair <K, V> [] map;`

fixing the generic map

return an `ArrayList<K>` instead of an `Array`

good general rule as well; ArrayLists are so much nicer to work with…

```
public ArrayList<K> keys () {
  ArrayList<K> keys = new ArrayList<>(count);
  for (int i = 0; i < count; i += 1) {
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public ArrayList<K> keys () {
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  Collections.sort(keys);
  return keys;
}
```

we can always add an element to an `ArrayList`,
this is a much better solution too for `private Pair <K, V> [] map;`

counting words with the generic map

```
private void run2() {
  Scanner scan = new Scanner(line).useDelimiter("\\W+");
  MapGen<String, Integer> map = new MapGen<>(100);




}
```

counting words with the generic map

```
private void run2() {
  Scanner scan = new Scanner(line).useDelimiter("\\W+");
  MapGen<String, Integer> map = new MapGen<>(100);
  while (scan.hasNext()) {
    String word = scan.next().toLowerCase();
    try {
    Integer prevCount = map.get(word);
    if ( prevCount == null ) {
      map.add(word, 1);
    } else {
      map.add(word, prevCount + 1);
    }
  }



}
```

counting words with the generic map

```
private void run2() {
  Scanner scan = new Scanner(line).useDelimiter("\\W+");
  MapGen<String, Integer> map = new MapGen<>(100);
  while (scan.hasNext()) {
    String word = scan.next().toLowerCase();
    try {
    Integer prevCount = map.get(word);
    if ( prevCount == null ) {
      map.add(word, 1);
    } else {
      map.add(word, prevCount + 1);
    }
  }
  for (String key: map.keys()) {
    System.out.println(key + ": " + map.get(key));
  }
}
```

counting words with the generic map

```
private void run2() {
  Scanner scan = new Scanner(line).useDelimiter("\\W+");
  MapGen<String, Integer> map = new MapGen<>(100);
  while (scan.hasNext()) {
    String word = scan.next().toLowerCase();
    try {
    Integer prevCount = map.get(word);
    if ( prevCount == null ) {
      map.add(word, 1);
    } else {
      map.add(word, prevCount + 1);
    }
  }
  for (String key: map.keys()) {
    System.out.println(key + ": " + map.get(key));
  }
}
```

```
be: 2
is: 1
not: 1
or: 1
question: 1
that: 1
the: 1
to: 2
```

limitations on subtypes: make subclass

```
class Person {
  protected String name;
  public Person(String name) { this.name = name; }
  @Override
  public String toString() {
    return "Person " + name;
  }
}
```

limitations on subtypes: make subclass

```
class Person {
  protected String name;
  public Person(String name) { this.name = name; }
  @Override
  public String toString() {
    return "Person " + name;
  }
}
class Student extends Person {
  protected int num;
  public Student(int num, String name) {
    super(name);
    this.num = num;
  }
  @Override
  public String toString() {
    return "Student " + name + " " + num;
  }
}
```

limitations on subtypes: this is fine

```
class Box <T> {
  private T e;
  public Box(T e) { this.e = e; }
  @Override
  public String toString() {
    return "Box{" + e + '}';
  }
}
```

limitations on subtypes: this is fine

```
class Box <T> {
  private T e;
  public Box(T e) { this.e = e; }
  @Override
  public String toString() {
    return "Box{" + e + '}';
  }
}
```

in some class:

```
private void run1 () {
  Box<Person> b1 = new Box<>(new Person("Alice"));
  Box<Person> b2 = new Box<>(new Student(1, "Bob"));
  System.out.println(b1 + " " + b2);
}
```

limitations on subtypes: this is fine

```
class Box <T> {
  private T e;
  public Box(T e) { this.e = e; }
  @Override
  public String toString() {
    return "Box{" + e + '}';
  }
}
```

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}
```

b2 contains a subtype of Person

limitations on subtypes: this is fine

```
class Box <T> {
  private T e;
  public Box(T e) { this.e = e; }
  @Override
  public String toString() {
    return "Box{" + e + '}';
  }
}
```

in some class:

```
private void run1 () {
  Box<Person> b1 = new Box<>(new Person("Alice"));
  Box<Person> b2 = new Box<>(new Student(1, "Bob"));
  System.out.println(b1 + " " + b2);
}
```

b2 contains a subtype of Person

```
Box{Person Alice} Box{Student Bob 1}
```

limitations on subtypes: still fine

```
private void print(Box<Person> b) {
  System.out.print(b);
}

private void run1 () {
  Box<Person> b1 = new Box<>(new Person("Alice"));
  Box<Person> b2 = new Box<>(new Student (1, "Bob"));
  print(b1);
  print(b2);
}
```

limitations on subtypes: still fine

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  print(b2);
}
```

works fine ☺

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  Box<Person> b2 = new Box<>(new Student (1, "Bob"));
  print(b1);
  print(b2);
}
```

works fine ☺

```
Box{Person Alice}
Box{Student Bob 1}
```

limitations on subtypes: this doesn't work

```
private void print(Box<Person> b) {
  System.out.print(b);
}

private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
  Box<Student> b2 = new Box<>(new Student(1,"Bob"));
  print(b1);
  print(b2);
}
```

limitations on subtypes: this doesn't work

```
private void print(Box<Person> b) {
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private void run2 () {
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private void print(Box<Person> b) {
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private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
  Box<Student> b2 = new Box<>(new Student(1,"Bob"));
  print(b1);
  print(b2);
}
```

unchanged

error: incompatible types: Box<Student> cannot be converted to Box<Person>

limitations on subtypes: this doesn't work

```
private void print(Box<Person> b) {
  System.out.print(b);
}

private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
  Box<Student> b2 = new Box<>(new Student(1,"Bob"));
  print(b1);
  print(b2);
}
```

unchanged

error: incompatible types: Box<Student> cannot be converted to Box<Person>

Solution: Wildcard Generic Types

wildcard generic types: bounded

```
private void print(Box<? extends Person> b) {
  System.out.print(b);
}

private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
  Box<Student> b2 = new Box<>(new Student(1,"Bob"));
  print(b1);
  print(b2);
}
```

wildcard generic types: bounded

```
private void print(Box<? extends Person> b) {
  System.out.print(b);
}

private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
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  print(b1);
  print(b2);
}
```

wildcard generic types: bounded

```
private void print(Box<? extends Person> b) {
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private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
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  print(b1);
  print(b2);
}
```

bounded wildcard generic

works fine ☺

wildcard generic types: bounded

```
private void print(Box<? extends Person> b) {
  System.out.print(b);
}

private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
  Box<Student> b2 = new Box<>(new Student(1,"Bob"));
  print(b1);
  print(b2);
}
```

bounded wildcard generic

works fine ☺

```
Box{Person Alice}
Box{Student Bob 1}
```

wildcard generic types: lower bound

```
private void print(Box<? super Student> b) {
  System.out.print(b);
}

private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
  Box<Student> b2 = new Box<>(new Student(1,"Bob"));
  print(b1);
  print(b2);
}
```

wildcard generic types: lower bound

```
private void print(Box<? super Student> b) {
  System.out.print(b);
}

private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
  Box<Student> b2 = new Box<>(new Student(1,"Bob"));
  print(b1);
  print(b2);
}
```

lower bound wildcard generic (weird example, see book chapter 19.7 for details!)

wildcard generic types: lower bound

```
private void print(Box<? super Student> b) {
  System.out.print(b);
}

private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
  Box<Student> b2 = new Box<>(new Student(1,"Bob"));
  print(b1);
  print(b2);
}
```

lower bound wildcard generic (weird example, see book chapter 19.7 for details!)

works fine ☺

wildcard generic types: lower bound

```
private void print(Box<? super Student> b) {
  System.out.print(b);
}

private void run2 () {
  Box<Person> b1  = new Box<>(new Person("Alice"));
  Box<Student> b2 = new Box<>(new Student(1,"Bob"));
  print(b1);
  print(b2);
}
```

lower bound wildcard generic (weird example, see book chapter 19.7 for details!)

works fine ☺

```
Box{Person Alice}
Box{Student Bob 1}
```

JOKE OF THE WEEK

a computer science student…

…was writing a note to his crush before lecture.
The student next to him grabbed the note.

student 1: You can't see that, it's private!

student 2: But we're in the same class!

providing similar actions for various container types

COLLECTIONS

the class Arrays

standard data types often need the same manipulations

- sorting, searching, equality, ..

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- we used the `Arrays.sort` in the assignments and above

the class Arrays

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`Arrays` provides useful operations on arbitrary arrays

- `fill`, `sort`, `binarySearch`, `equals, ..`
- we used the `Arrays.sort` in the assignments and above

`Arrays` does ***not*** box an ordinary array;

- it has no attributes
- static methods of `Arrays` take the array as argument
  e.g. `Arrays.sort( words );`

sometimes the size of a data type is unknown

`Strings` have a fixed length

`StringBuffers` can be changed

- it is always possible to add a character

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- it is always possible to add a character

ordinary arrays have a fixed length

`ArrayList` and **`LinkedList`** have a variable length

- it is always possible to add an element,
  at any place
- we can remove an element without the need to shift elements
- in contrast to **`Arrays`** these are real classes containing the element
- these classes implement the interface **`List<T>`**

a map of arbitrary size 1 / 2

```
public class MapList <K extends Comparable<K>, V> {
  protected List <Pair <K, V>> map;
```

a map of arbitrary size 1 / 2

```
public class MapList <K extends Comparable<K>, V> {
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  public MapList() {
    map = new ArrayList<>();
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public class MapList <K extends Comparable<K>, V> {
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  }
  public void add(K key, V val) {
    for (Pair<K, V> pair : map) {
      if (pair.getKey().equals(key)) {
        pair.setVal(val);
        return;
      }
    }
    map.add(new Pair<>(key, val));
  }
```

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no length limit

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List is interface

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  }
```

List is interface

no length limit

ArrayList is class implementing **List**

no test for null

always fits

a map of arbitrary size 2 / 2

```
public V get(K key) {
  for (Pair<K, V> pair : map)
    if (pair.getKey().equals(key))
      return pair.getVal();
  return null;
}
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a map of arbitrary size 2 / 2

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  public V get(K key) {
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      if (pair.getKey().equals(key))
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    return null;
  }
  public List<K> keys () {
    List<K> keys = new ArrayList<>();
    for (Pair<K, V> pair : map)
      keys.add(pair.getKey());
    Collections.sort(keys);
    return keys;
  }
}
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Collections instead of **Arrays**

the interface `Collection`

we have several containers in Java

- `String`, `StringBuffer`, `ArrayList`, `LinkedList`, `Vector`, `Set`

many similar operations on these containers

- `isEmpty`, `contains`, `equals`, `size`

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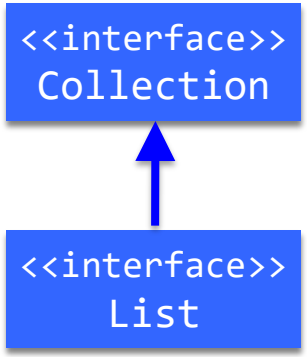
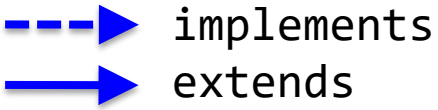
warning: there is also a **class** `Collections`

- **`Collections`** is similar to **`Arrays`**: useful manipulations using static methods
- don't confuse them

Collection Interface family





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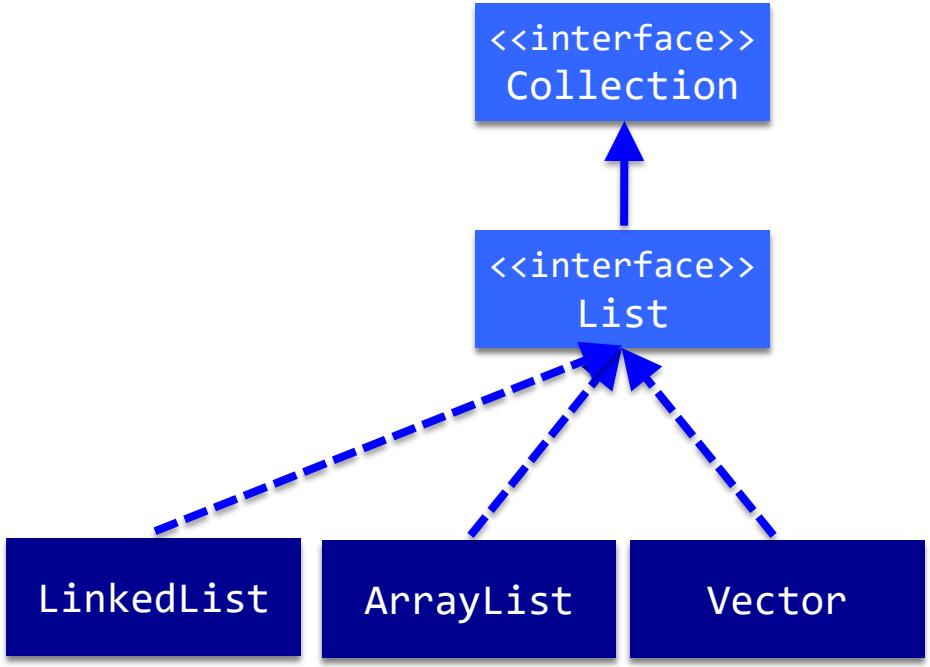
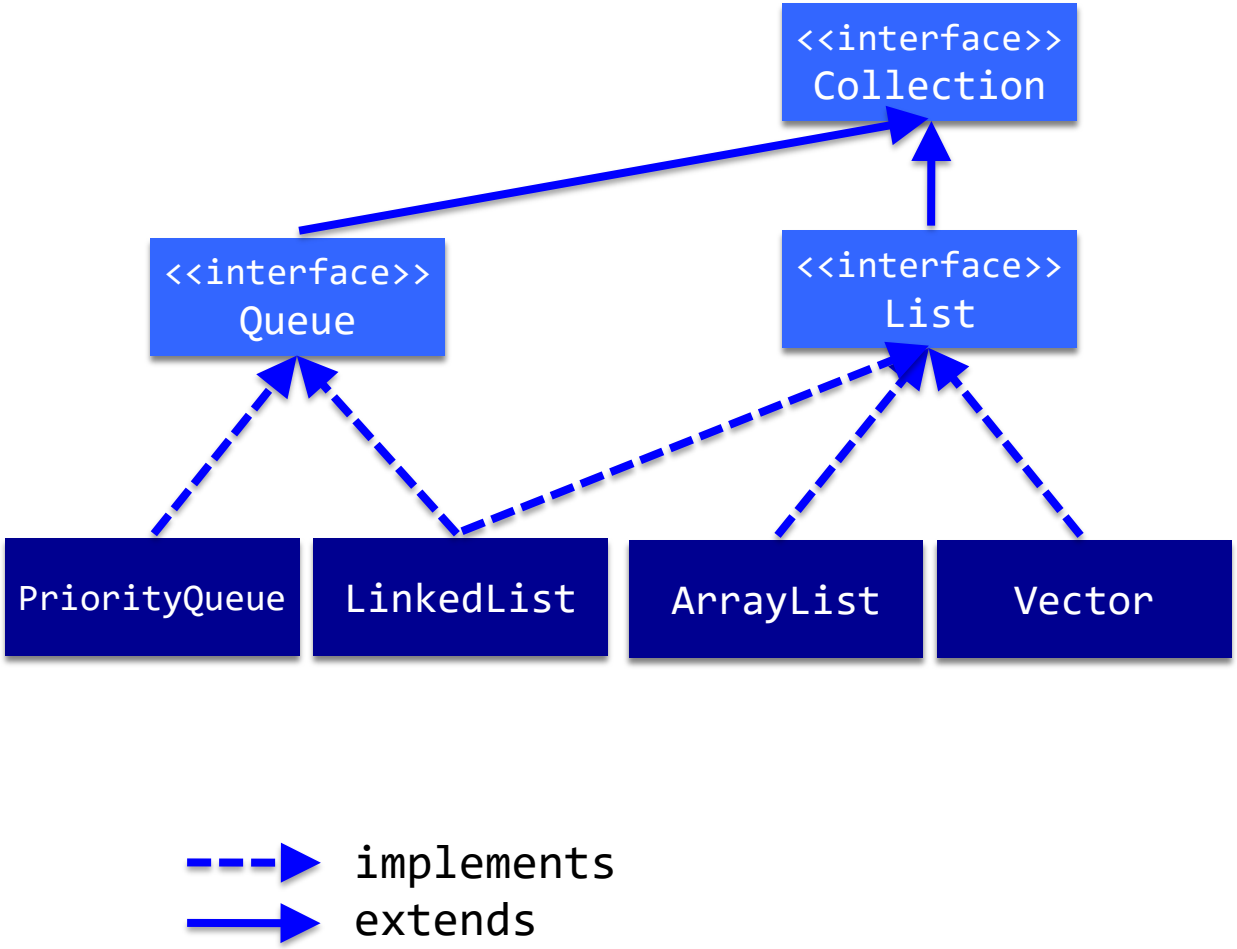


implements

extends

Collection Interface family



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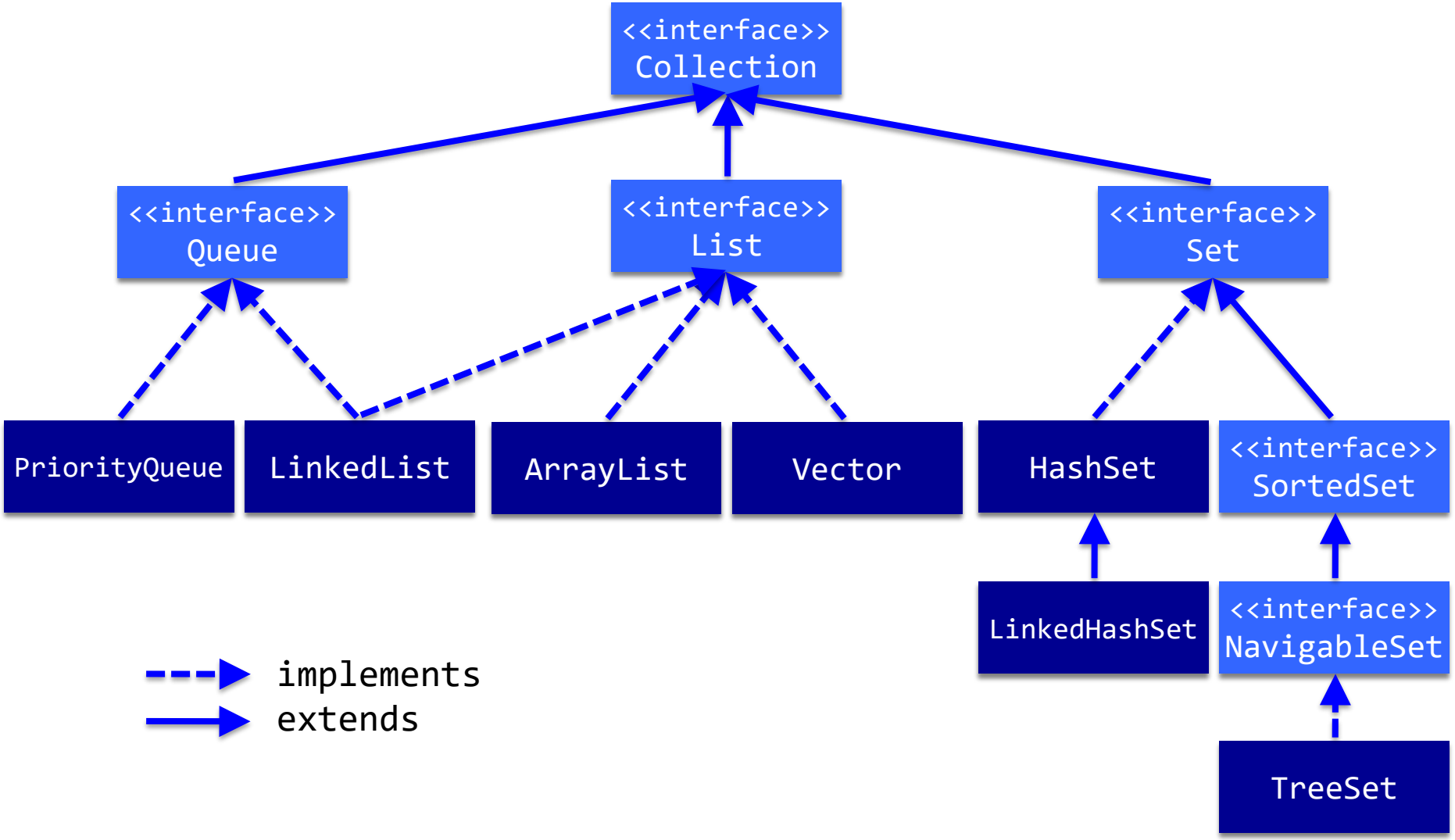
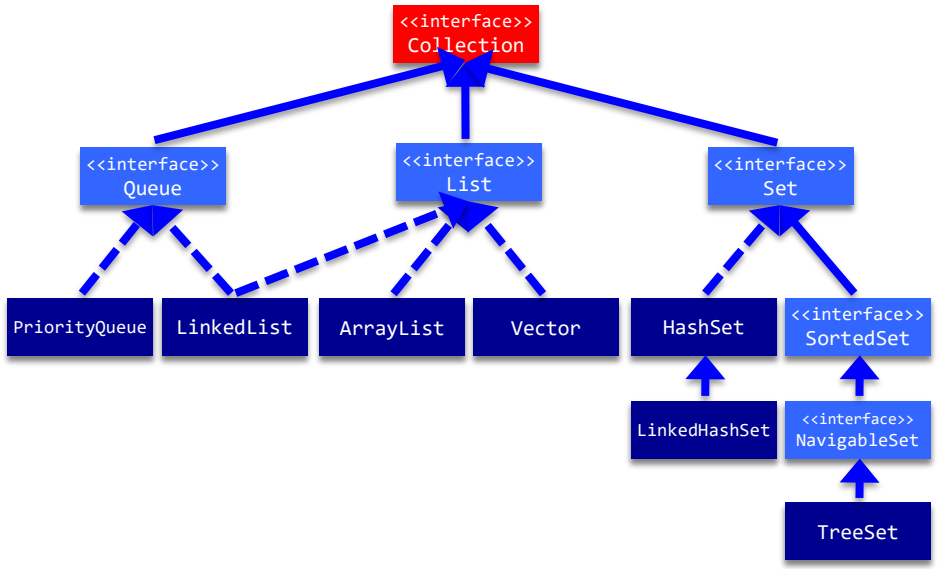


main methods in Interface Collection<E>

```
boolean add(E e)
```



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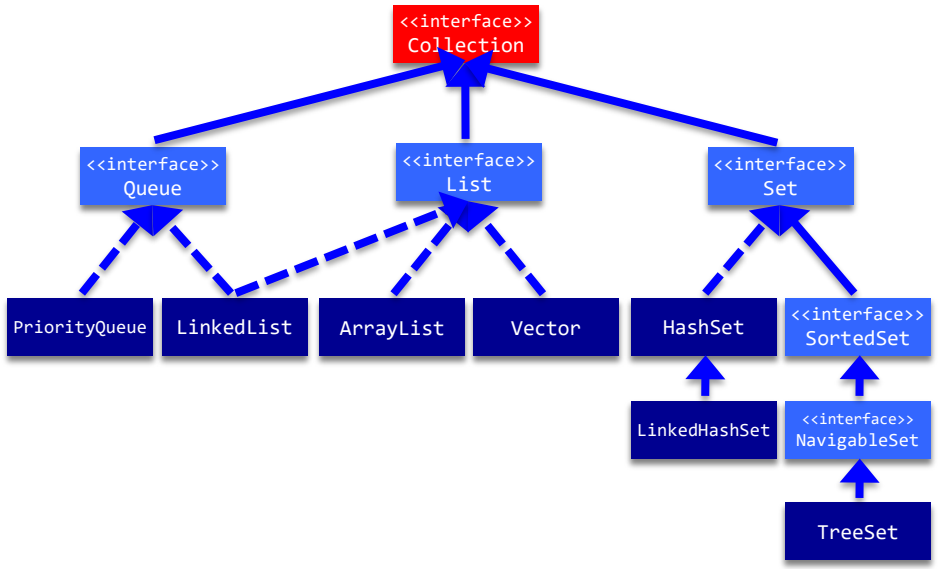

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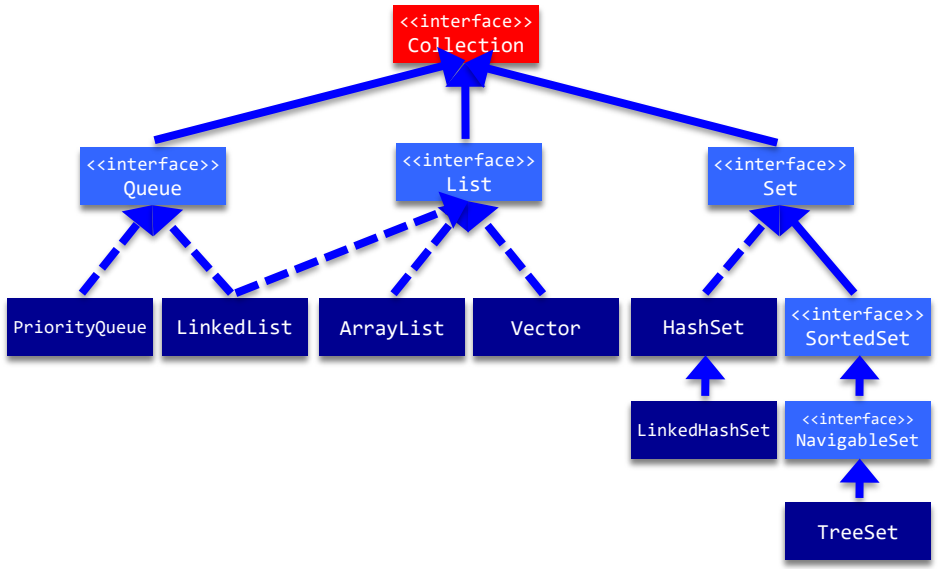

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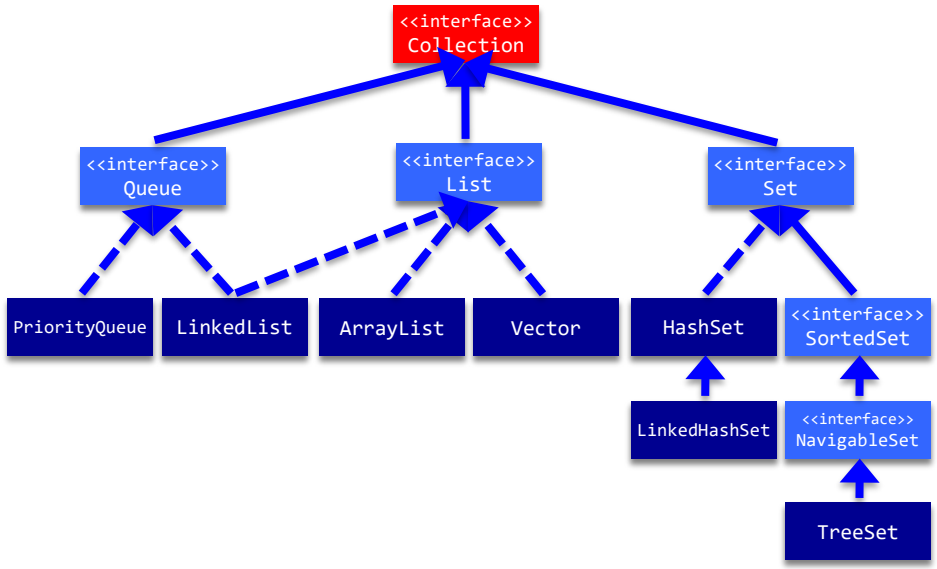

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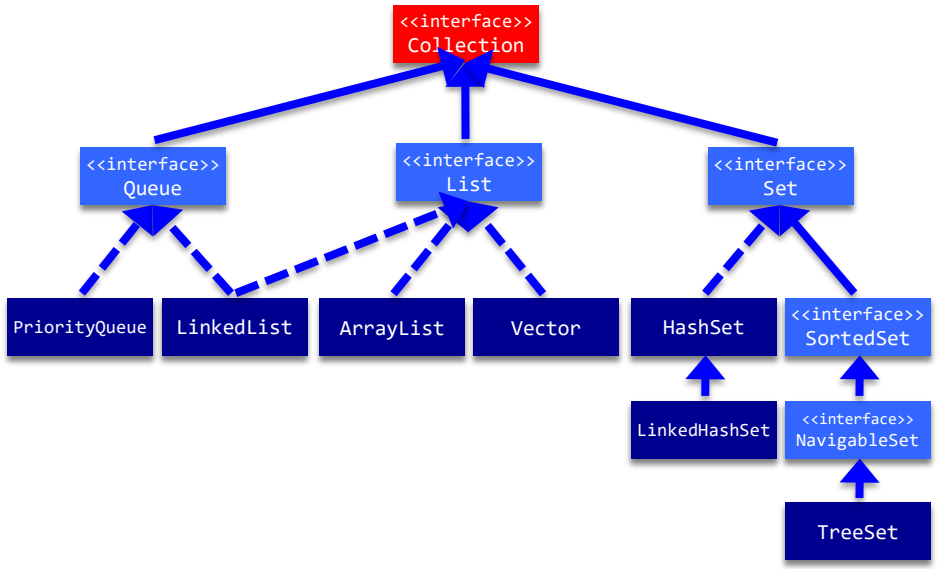

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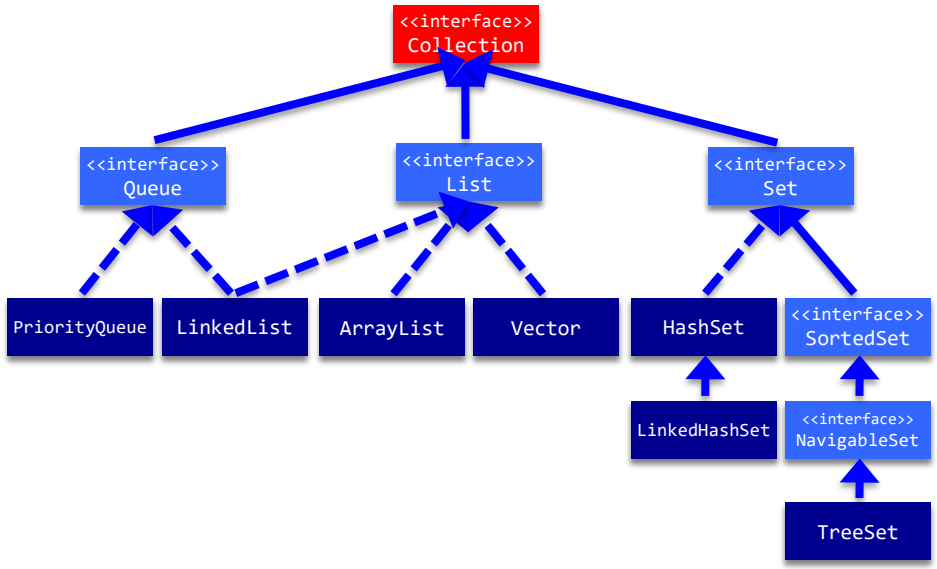

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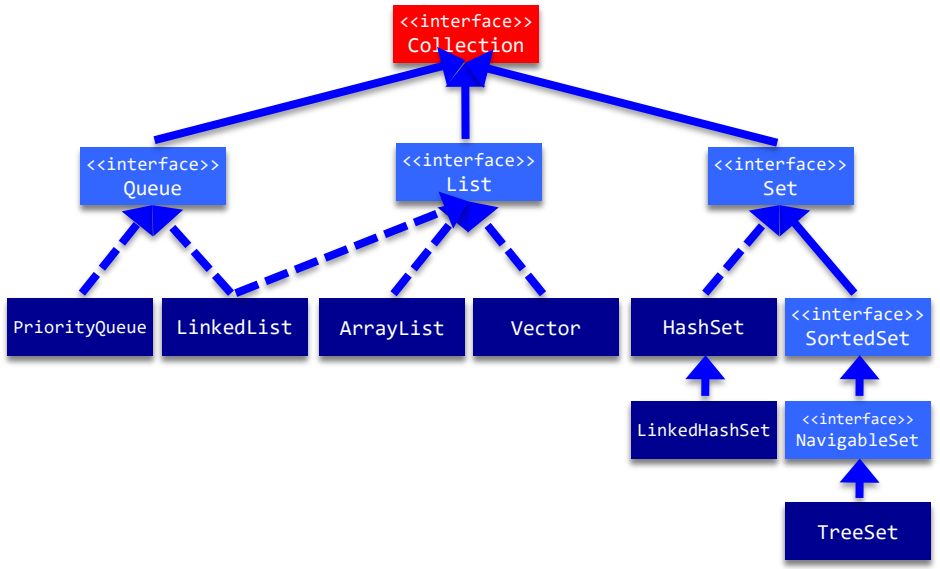

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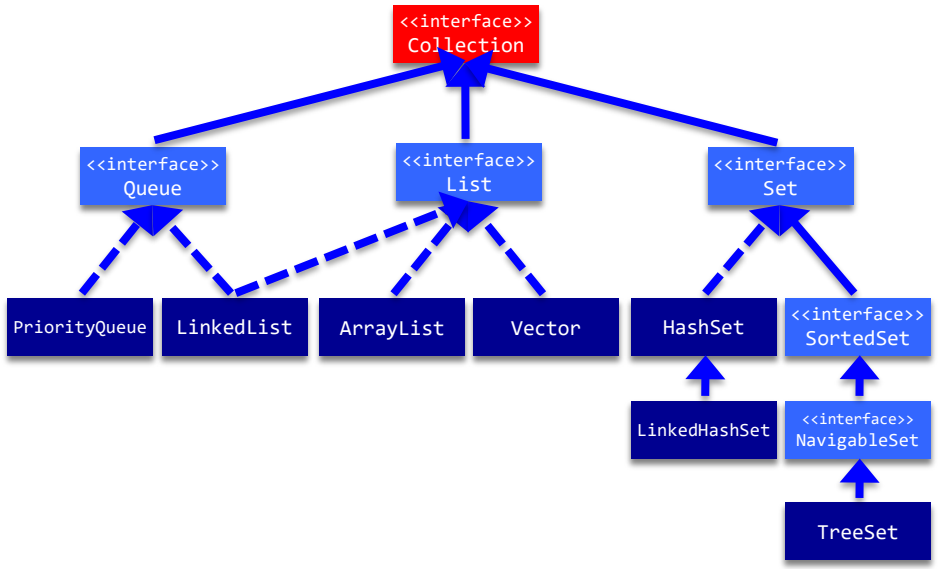

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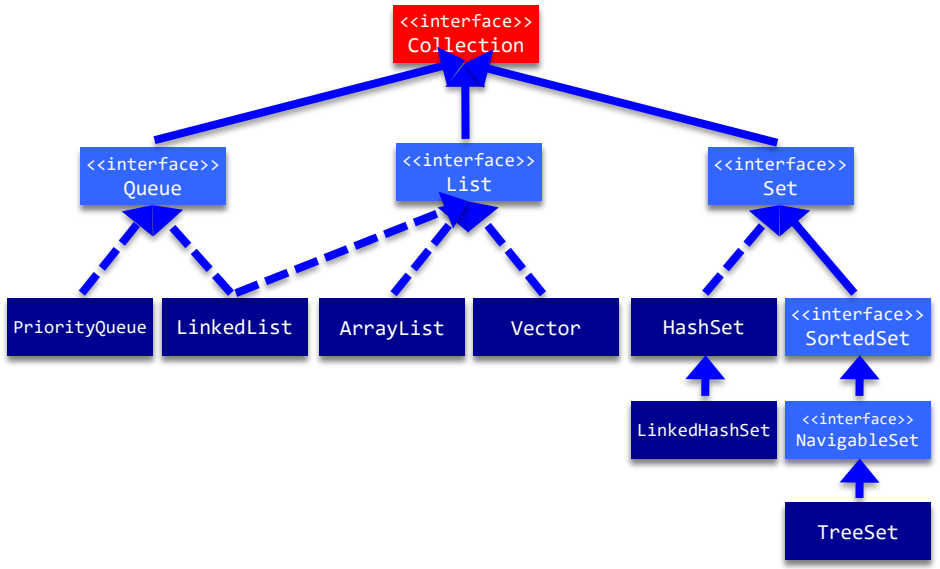

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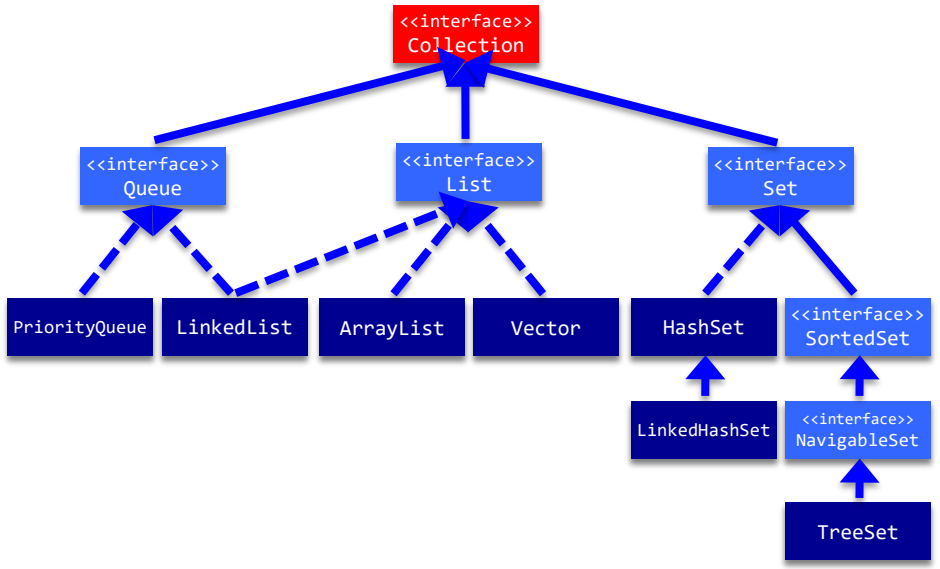

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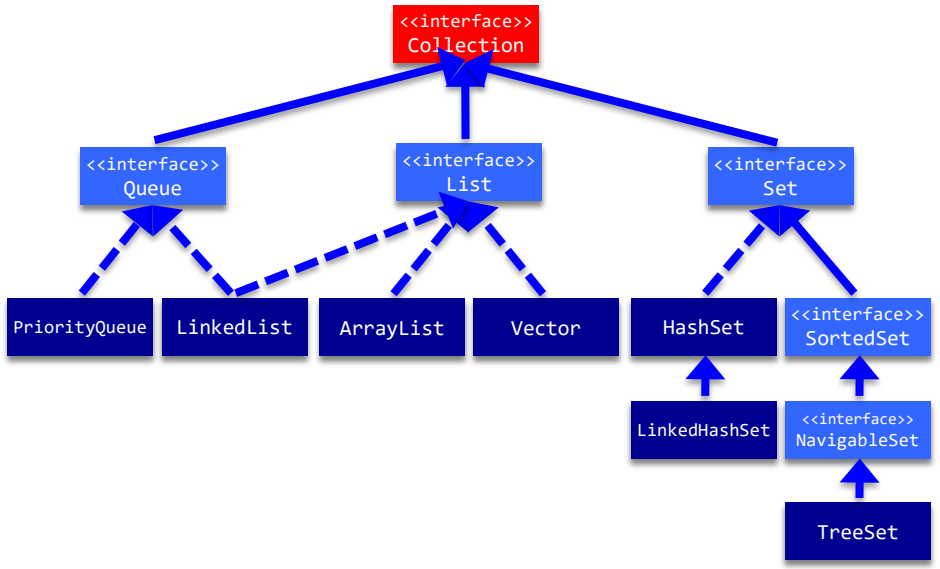

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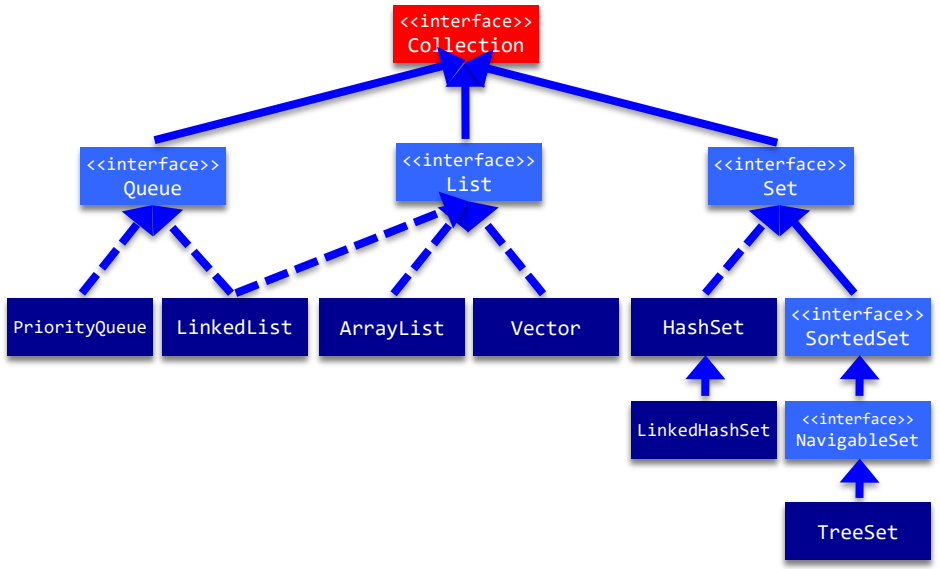

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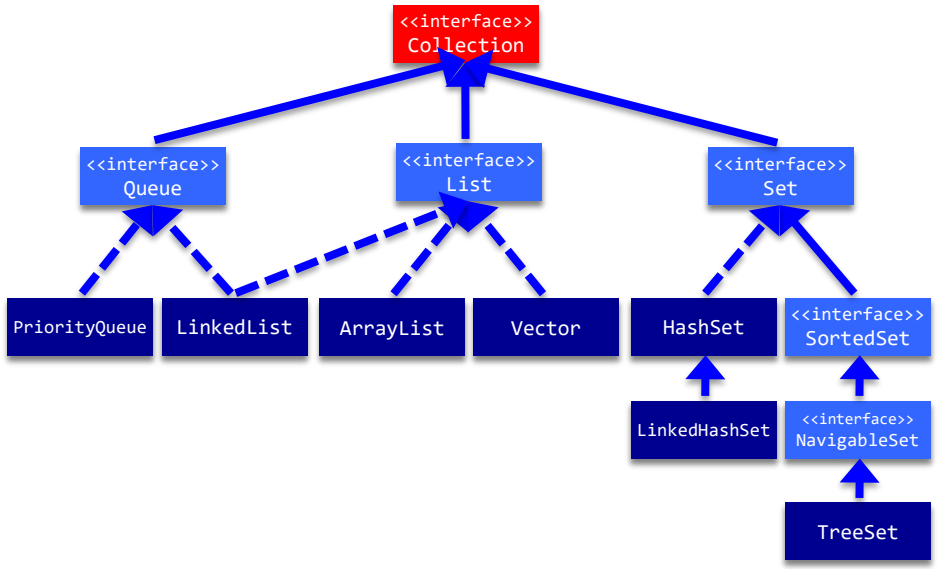

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<T> T[] toArray(T[] a)
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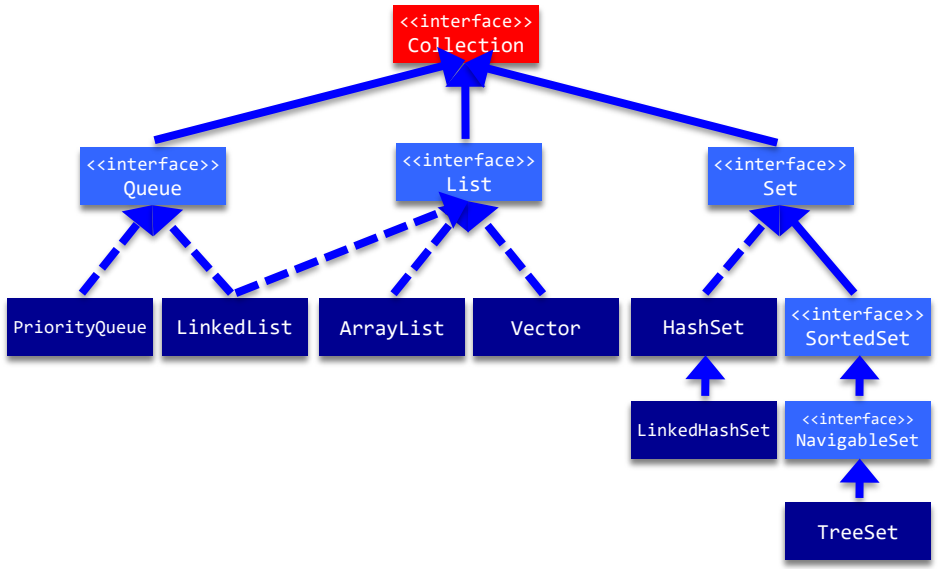

iterators

`Iterator` offers a standard way to scan and handle all elements of a collection

- this is an interface; many implementations possible

the `Iterator` keeps track of the current element in a collection

there are methods to advance to the next element and to change the collection

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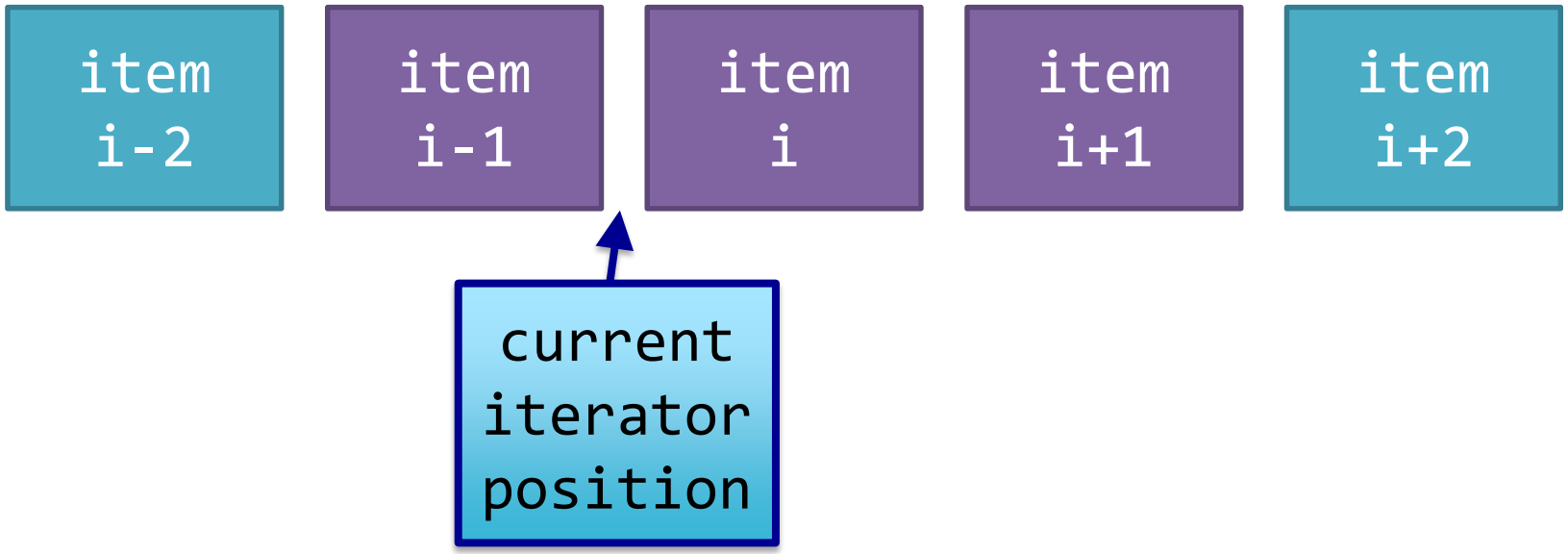
note: no `previous()`!

`Iterator` interface

an **`Iterator`** is conceptually *between* elements;
it does not refer to a particular object



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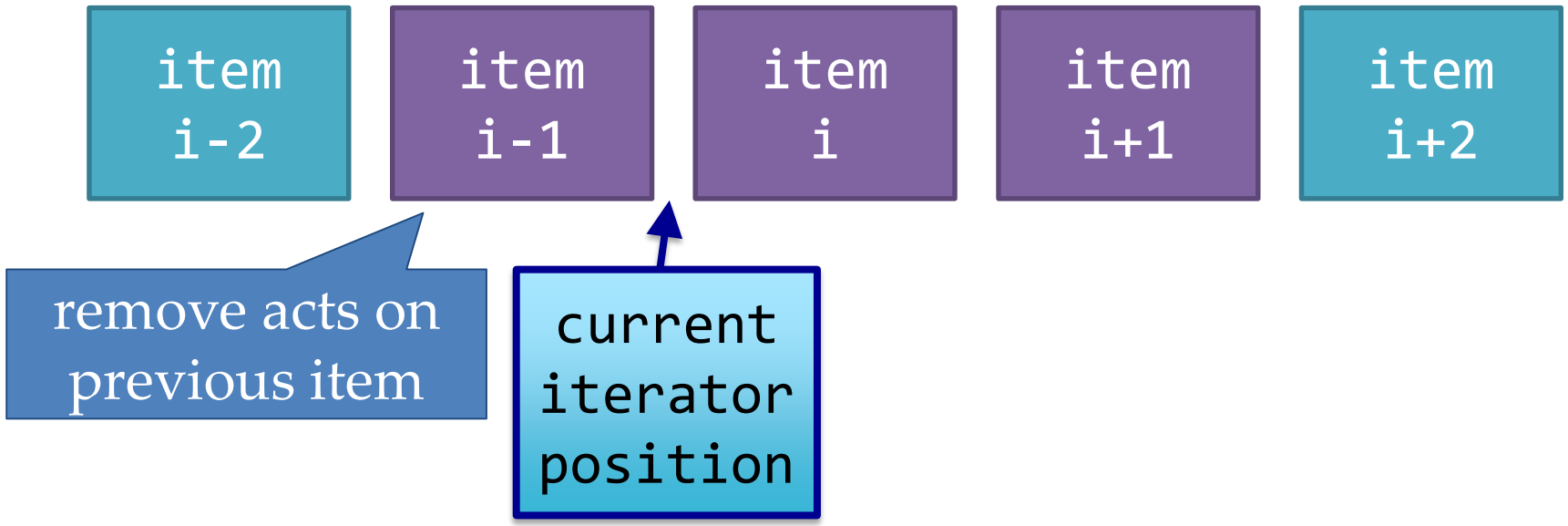

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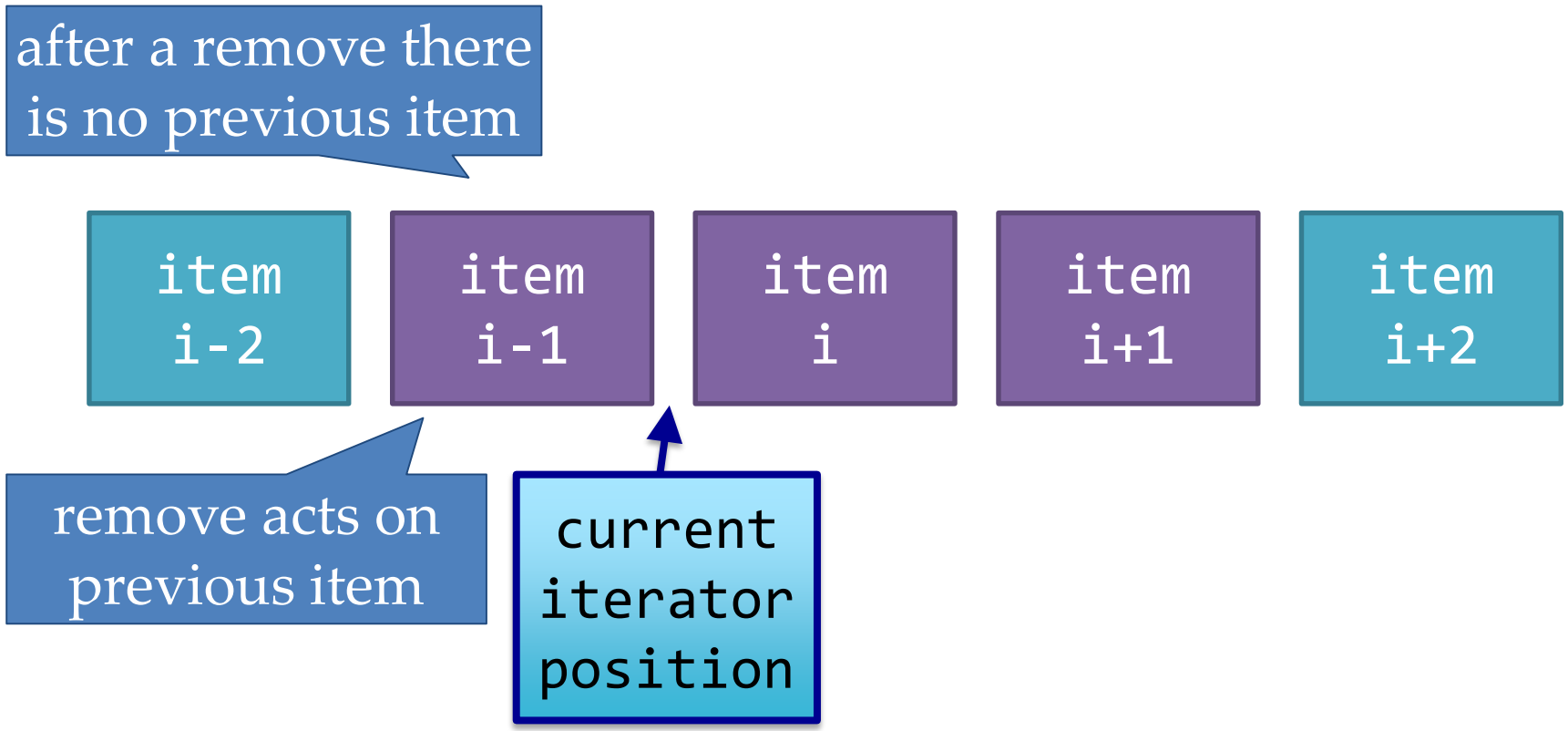

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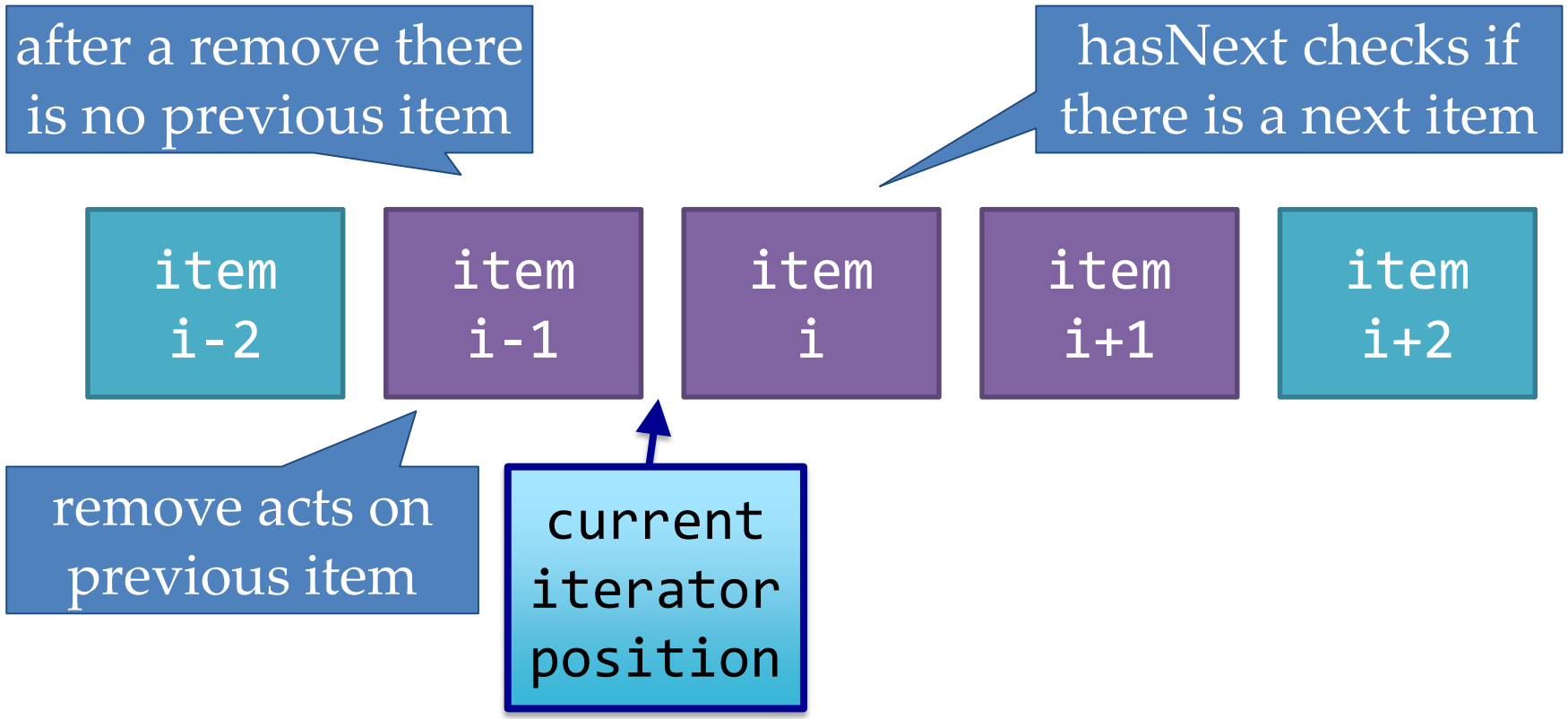

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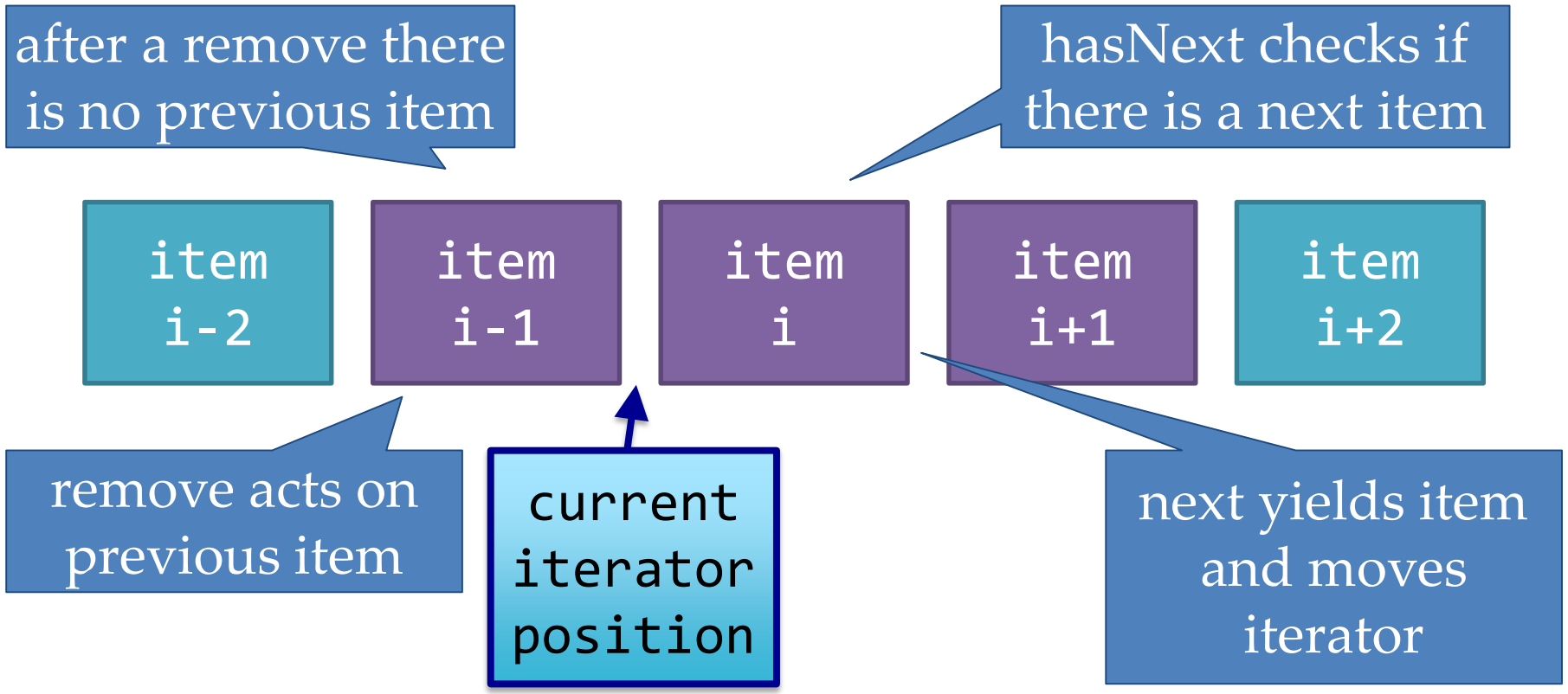

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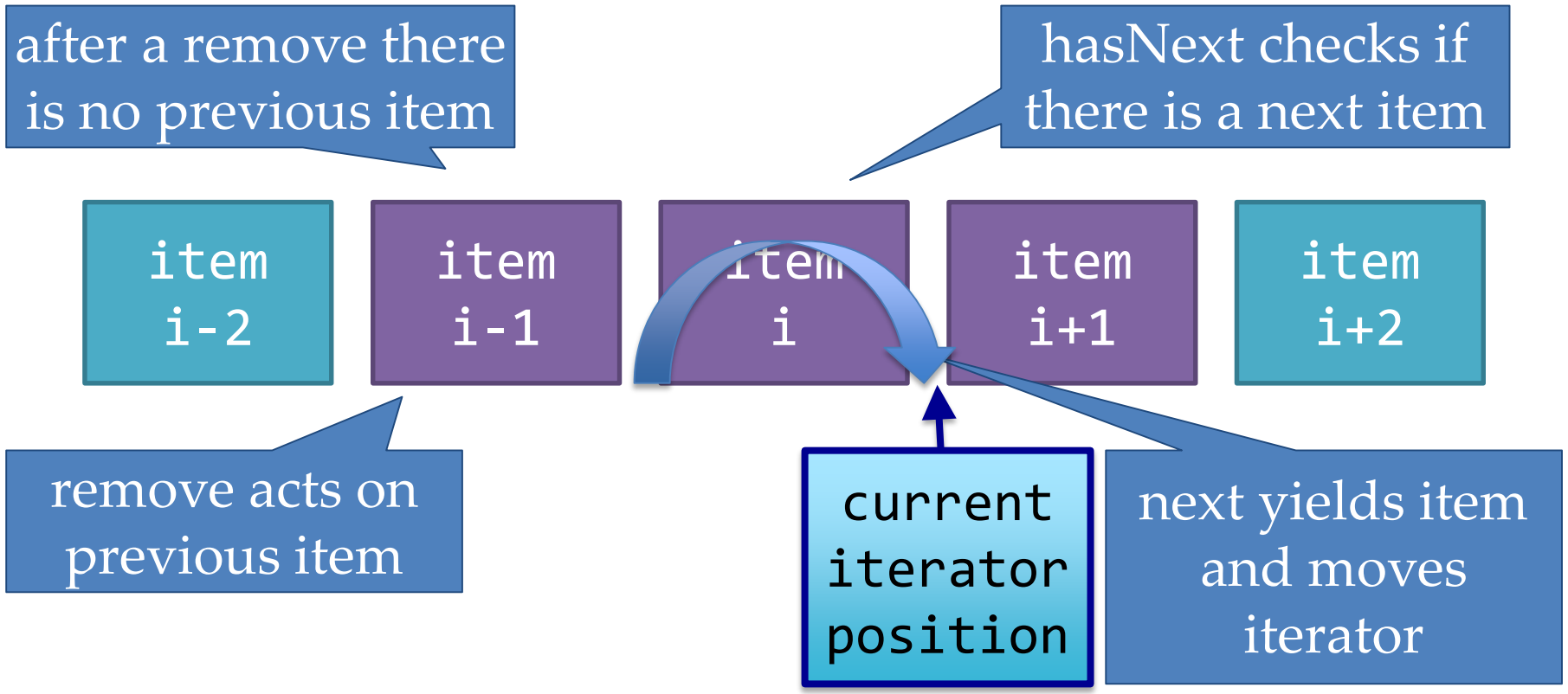

iterator applications in our Map: getting element

```
public V get(K key) {
  Iterator<Pair<K, V>> it = map.iterator();
  while (it.hasNext()) {
    Pair<K, V> pair = it.next();
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note how to get an iterator for `map`

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  Iterator<Pair<K, V>> it = map.iterator();
  while (it.hasNext()) {
    Pair<K, V> pair = it.next();
    if (pair.getKey().equals(key)) {
      return pair.getVal();
    }
  }
  return null;
}
```

note how to get an iterator for `map`

note: `next` yields the element **and** moves the iterator!

iterator applications in our Map: getting element

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note how to get an iterator for `map`

note: `next` yields the element **and** moves the iterator!

using `next()` twice gives two elements

The most frequent error with iterators

iterator applications in our Map: removing element

```
public boolean remove (K key) {
  Iterator<Pair<K, V>> it = map.iterator();
  while (it.hasNext())
    if (it.next().getKey().equals(key)) {
      it.remove();
      return true;
  }
  return false;
}
```

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single operation on list element; no need to keep it around in a variable

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single operation on list element; no need to keep it around in a variable

this cannot be done by an enhanced for-loop because the Iterator is hidden!

be careful using multiple `Iterators` for the same `Iterable`

iterators are very handy to scan collections

- list, set, queue, ..

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what happens when the collection changes while the iterators scans it?

- `hasNext()` yields `true`, but the element is removed
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- always when changes might effect the iterator

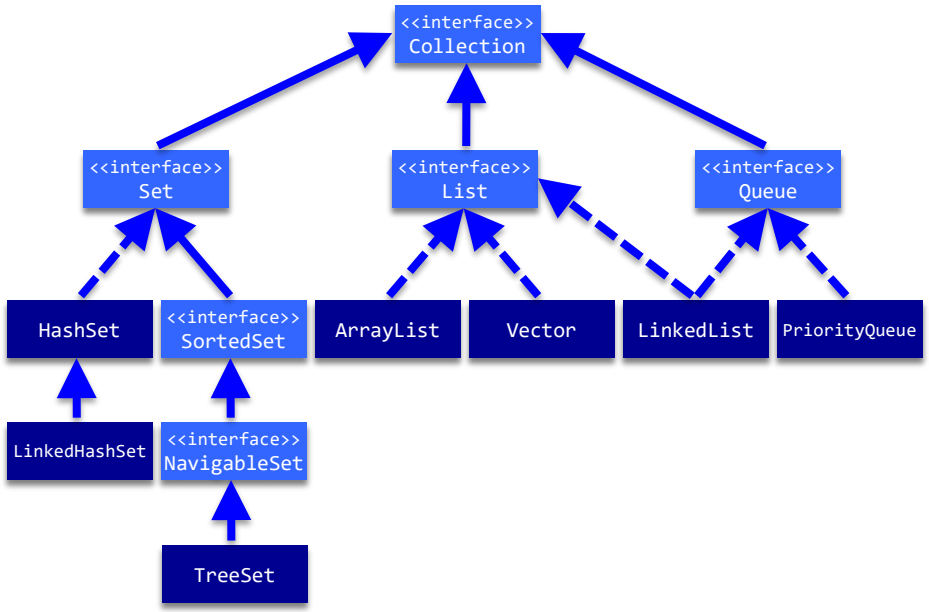
`next()` throws an `NoSuchElementException` when there is no element during normal iteration

`remove()` throws an `IllegalStateException` when there is nothing to be removed

Lists

interface **`List`** is an extension of **`Collection`**

- `List` adds methods to manipulate elements via indices
  - `void add(int index, E element)`
  - `E get(int index)`
  - `E remove (int index)`
  - `E set (int index, E element)` …



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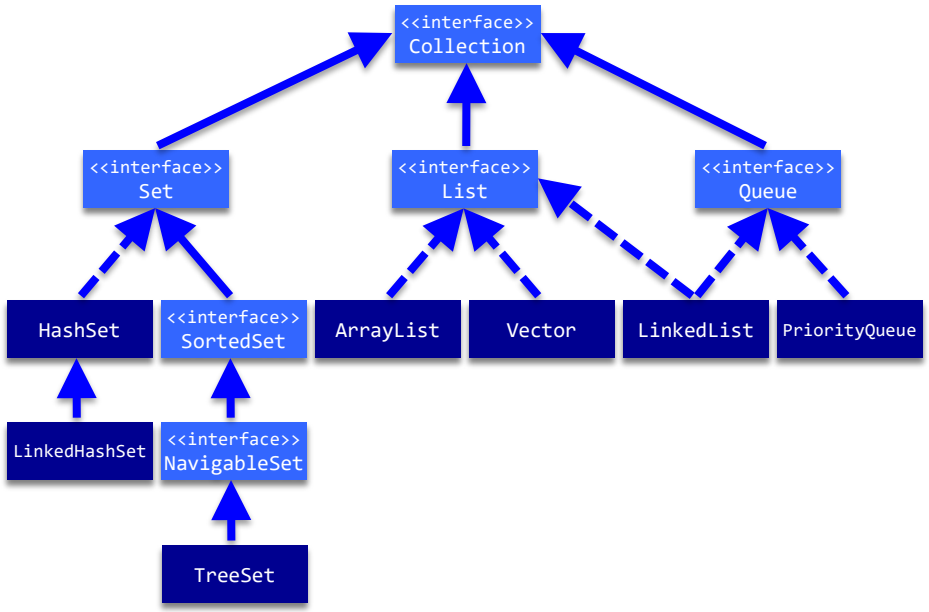
`ArrayList` implements the interface **`List`**

other implementations are
`LinkedList` and **`Vector`**



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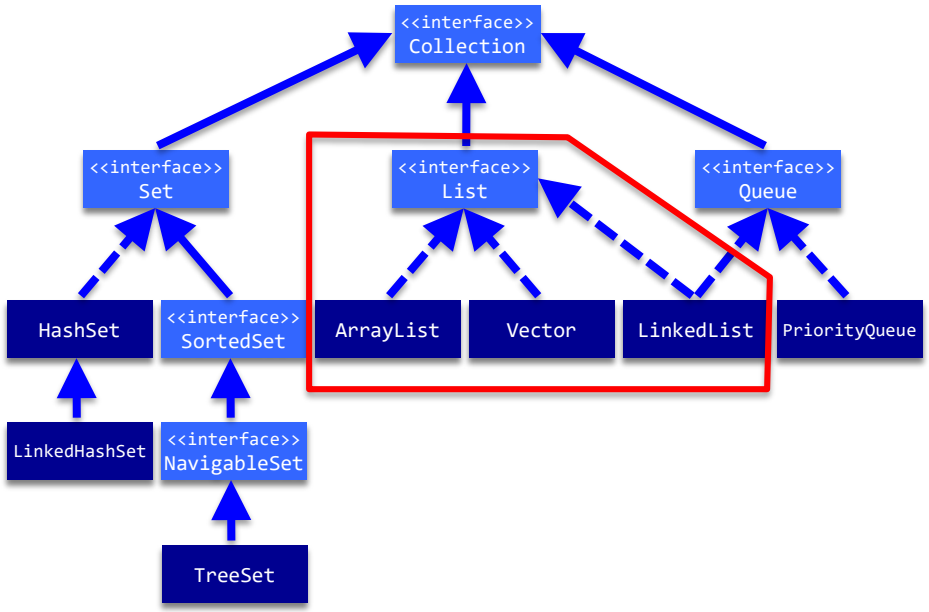
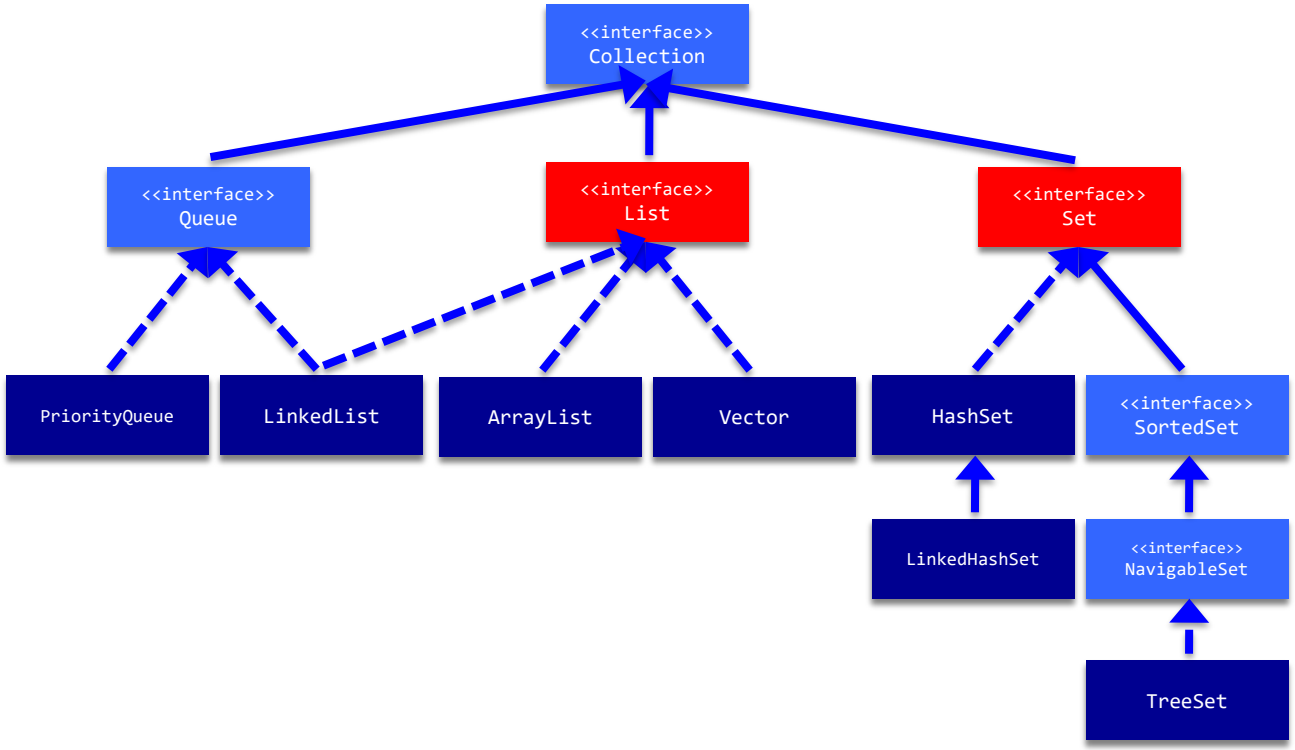


collection relationships

Set

- does not contain duplicates
- can (sometimes) be sorted !



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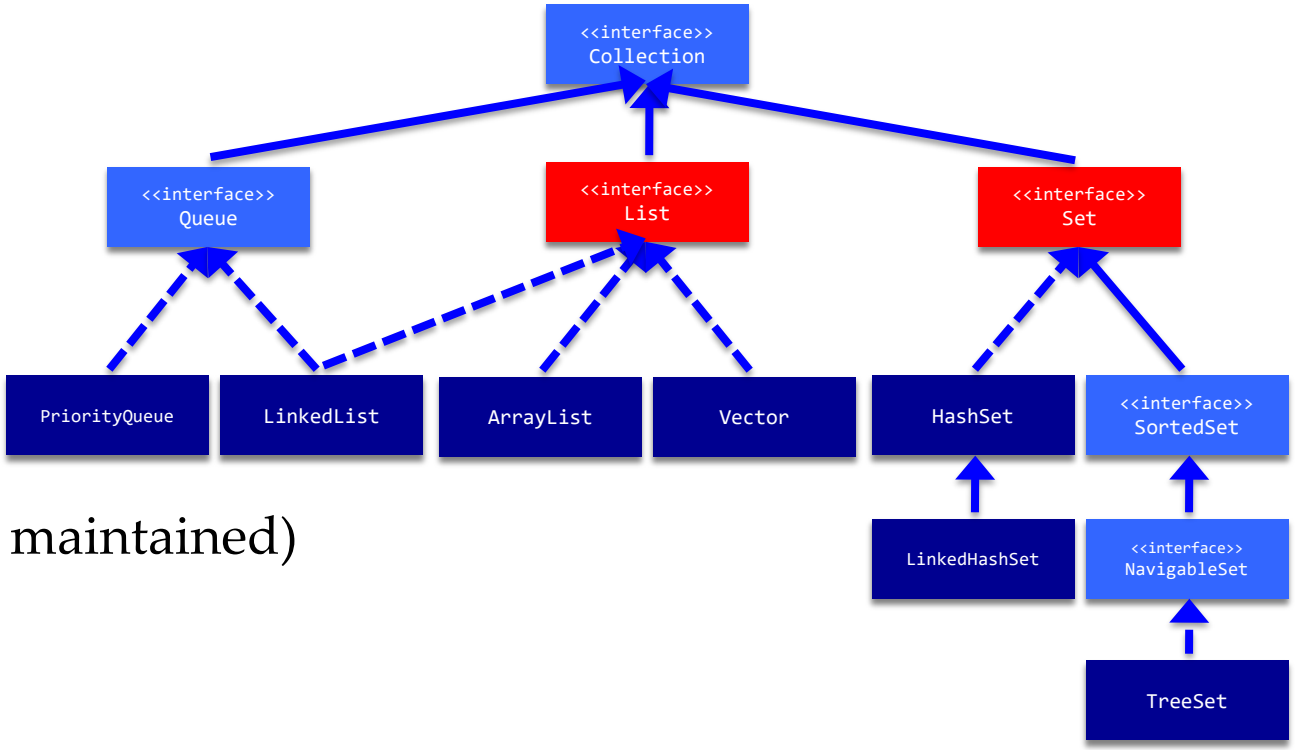

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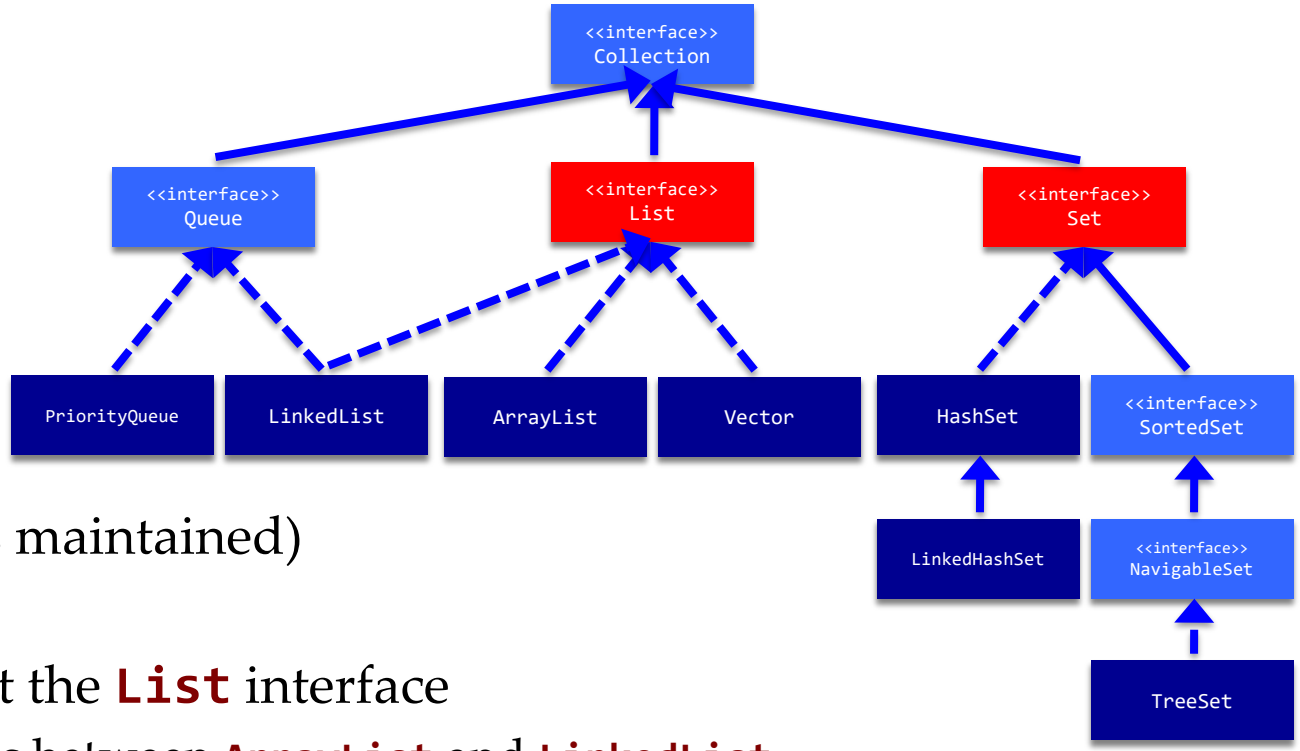

`Set`

- does not contain duplicates
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`List`

- elements are ordered (insertion order is maintained)
- elements can occur more than once
- `ArrayList` and `LinkedList` implement the `List` interface
  - next lecture we will discuss the differences between `ArrayList` and `LinkedList`
- `Vector` is very similar to `ArrayList` in API,
  vectors are thread-safe and hence somewhat slower

the class `Collections`

do not confuse it with the interface `Collection`

- contains algorithms for collections
- like `Arrays` for arrays

implemented algorithms:

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- contains algorithms for collections
- like `Arrays` for arrays

implemented algorithms:

```
sort, binarySearch, reverse, shuffle,
fill, copy, min, max, addAll,
frequency, disjoint
```

three ways to access all list elements

```
for (int i = 0; i < list.size(); i += 1) {



}
```

three ways to access all list elements

```
for (int i = 0; i < list.size(); i += 1) {
    Card card = list.get(i);



}
```

three ways to access all list elements

```
for (int i = 0; i < list.size(); i += 1) {
    Card card = list.get(i);
    if (card.face == Card.Face.Queen) {
        System.out.println("Queen1: " + card);
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}
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}
        for (Card card : list) {
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                System.out.println("Queen2: " + card);
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for (Card card : list) {
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        System.out.println("Queen2: " + card);
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```

+ compact
+ efficient
− list cannot be changed

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Iterator<Card> iter = list.iterator();
while (iter.hasNext()) {

}
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Iterator<Card> iter = list.iterator();
while (iter.hasNext()) {
    Card card = iter.next();
    if (card.face == Card.Face.Queen) {
        System.out.println("Queen3: " + card);
    }
}
```

three ways to access all list elements

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for (int i = 0; i < list.size(); i += 1) {
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    }
}
```

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for (Card card : list) {
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− list cannot be changed

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Iterator<Card> iter = list.iterator();
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    }
}
```

+ efficient
+ flexible
+ not restricted to loop
! remove only last item

lessons learned

generics written as <T>

- make classes more general
- improves static typing

lessons learned

generics written as `<T>`

- make classes more general
- improves static typing

`Collection`: a family of generic data structures

- **`List`**
  - ordered like arrays

lessons learned

generics written as `<T>`

- make classes more general
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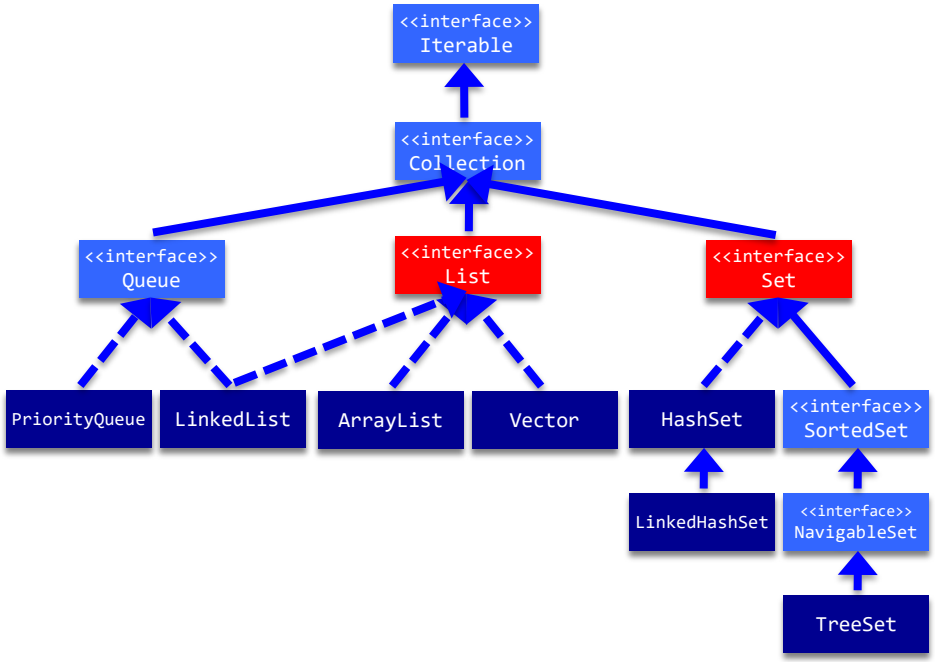
`Collection`: a family of generic data structures

- **`List`**
  - ordered like arrays
  - we can always add, insert or delete elements
- **`Set, Queue,`** ..



- **`Iterator`** is the standard way to access collections
  - `hasNext()`, `next()`, `remove()`

- **`Collections`** & **`Arrays`**: classes with convenience methods

Lecture 6: Generic & Recursive Data Structures