COMP 250
INTRODUCTION TO COMPUTER SCIENCE

Lecture 16 – Comparable and Iterable

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FROM LAST CLASS

- Interfaces
- Generics

WORKING TOWARD GENERICS

- Suppose I'd like to create a class that defines a new type `Cage`. I would like to use this in a class called `Kennel` where I have a bunch of objects of type `Dog`.
- What if later on I also happen to need cages for objects of type `Bird`?
- Can I use the same class? Should I create a new class with the same features but where instead of `Dog` I use `Bird`? Is there a better solution?

```
public class Cage {
    private Dog occupant;

    public void lock(Dog p) {
        this.occupant = p;
    }

    public Dog peek() {
        return this.occupant;
    }

    public void release() {
        this.occupant = null;
    }
}
```

GENERICS IN JAVA

- A generic type is a class or interface that is parameterized over types. We use angle brackets (<>) to specify the type parameter.
- Example →

```
public class Cage<T> {
    private T occupant;

    public void lock(T p) {
        this.occupant = p;
    }

    public T peek() {
        return this.occupant;
    }

    public void release() {
        this.occupant = null;
    }
}
```

EXAMPLE – CAGE<>

We can now create cages containing different type of objects, depending on the need:

```
Cage<Dog> crate = new Cage<Dog>();
// now inside crate we can lock only Dogs!
Dog snoopy = new Dog();
crate.lock(snoopy);

Cage<Bird> birdcage = new Cage<Bird>();
// if we call lock on birdcage we must provide a Bird as input.
Bird tweety = new Bird();
birdcage.lock(tweety);

// peek() called on crate returns a Dog,
// peek() called on birdcage returns a Bird!
Dog d = crate.peek();
Bird b = birdcage.peek();
```

GENERICS TYPE NAMING CONVENTIONS

- Java Generic Type Naming convention helps us understanding code easily.

- Usually type parameter names are single, uppercase letters to make it easily distinguishable from java variables. The most commonly used type parameter names are:
  - E – Element
  - K – Key (Used in Map)
  - N – Number
  - T – Type
  - V – Value (Used in Map)
  - S,U,V etc. – 2nd, 3rd, 4th types

EXAMPLE – LIST INTERFACE

java.util

Interface List<E>

Type Parameters:

`E - the type of elements in this list`

All Superinterfaces:

`Collection<E>, Iterable<E>`

All Known Implementing Classes:

`AbstractList, AbstractSequentialList, ArrayList, AttributeList, CopyOnWriteArrayList, LinkedList, RoleList, RoleUnresolvedList, Stack, Vector`

https://docs.oracle.com/javase/8/docs/api/java/util/List.html

EXAMPLE – LIST INTERFACE

```
public interface List<E> extends Collection<E>{
    boolean add(E e);
    void add(int i, E e);
    boolean isEmpty();
    E get(int i);
    E remove(int i);
    int size();
    :
}
```

Some of the methods are inherited from the interface Collection, while others are declared inside List.

EXAMPLE – LIST INTERFACE

The documentation explains exactly how each of these method should behave. For example:

add

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

Appends the specified element to the end of this list (optional operation).

Lists that support this operation may place limitations on what elements may be added to this list. In particular, some lists will refuse to add null elements, and others will impose restrictions on the type of elements that may be added. List classes should clearly specify in their documentation any restrictions on what elements may be added.

Specified by:

`add` in interface `Collection<E>`

Parameters:

`e` - element to be appended to this list

Returns:

`true` (as specified by `Collection.add(E)`)

EXAMPLE – LIST INTERFACE

The documentation explains exactly how each of these method should behave. For example:

add

`boolean add(E e)`

Ensures that this collection contains the specified element (optional operation). Returns `true` if this collection changed as a result of the call. (Returns `false` if this collection does not permit duplicates and already contains the specified element.)

Collections that support this operation may place limitations on what elements may be added to this collection. In particular, some collections will refuse to add `null` elements, and others will impose restrictions on the type of elements that may be added. Collection classes should clearly specify in their documentation any restrictions on what elements may be added.

If a collection refuses to add a particular element for any reason other than that it already contains the element, it *must* throw an exception (rather than returning `false`). This preserves the invariant that a collection always contains the specified element after this call returns.

Parameters:

`e - element whose presence in this collection is to be ensured`

Returns:

`true if this collection changed as a result of the call`

EXAMPLE – ARRAYLIST

```
public class ArrayList<E> implements List<E>{
    boolean add(E e) {...}
    void add(int i, E e) {...}
    boolean isEmpty() {...}
    E get(int i) {...}
    E remove(int i) {...}
    int size() {...}
    void ensureCapacity(int i) {...}
    void trimToSize() {...}
}
```

All of the methods from inherited from List are implemented. In addition, others are declared and implemented in ArrayList.

EXAMPLE – LINKEDLIST

```
public class LinkedList<E> implements List<E>{
    boolean add(E e) {...}
    void add(int i, E e) {...}
    boolean isEmpty() {...}
    E get(int i) {...}
    E remove(int i) {...}
    int size() {...}
    void addFirst(E e) {...}
    void addLast(E e) {...}
}
```

All of the methods from inherited from List are implemented. In addition, others are declared and implemented in LinkedList.

HOW ARE INTERFACES USED?

```
List<String> greetings;

greetings = new ArrayList<String>();
greetings.add("Hello");
   :
greetings = new LinkedList<String>();
Greetings.add("Good day!");
```

Interfaces define new data types. We can create variables of those type and assign to them any value referencing to instances of classes that implement the specified interface!

HOW ARE INTERFACES USED?

```
public void myMethod(List<String> list) {
    :
    list.add("one more");
    :
    list.remove(3);
    :
}
```

Whenever an object of type List is required, any instance of any of the classes that implement List can be used.

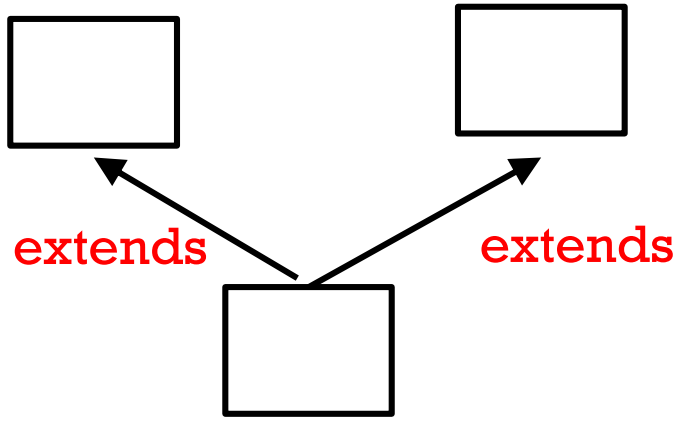
So, in this case, `myMethod()` can be called both with an ArrayList or a LinkedList as a parameter.

HOW ARE INTERFACES USED?

```
public void myMethod(List<String> list) {
    :
    list.add("one more");
    :
    list.remove(3);
    :
    list.addLast("Bye bye"); // compile-time error. Why??
}
```

INHERITANCE

Remember that a class (abstract or not) cannot extend more than one class (abstract or not).

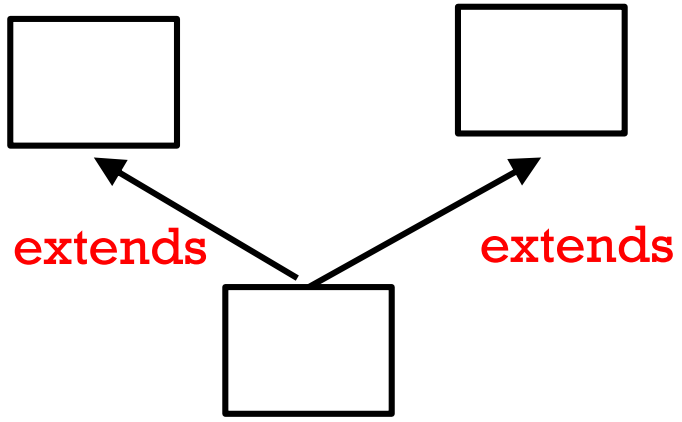


Not allowed!

- Why not?

INHERITANCE

Remember that a class (abstract or not) cannot extend more than one class (abstract or not).

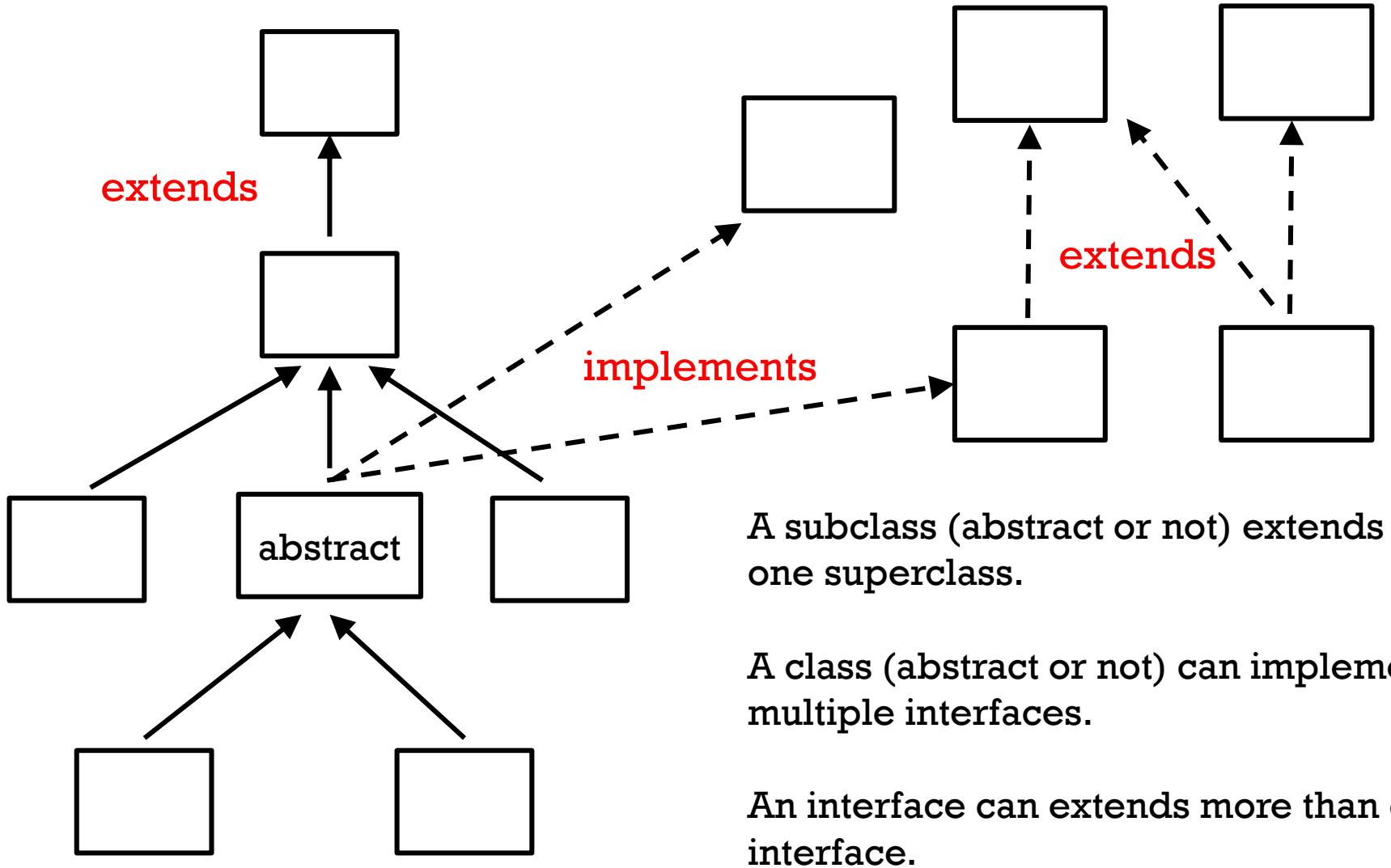


Not allowed!

- Why not? *The problem could occur if two superclasses have implemented methods with the same signature. Which would be inherited by the subclass?*

classes (abstract or not)

interfaces

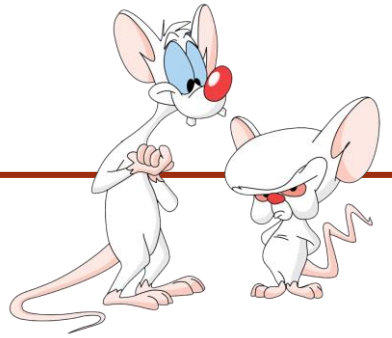


A subclass (abstract or not) extends exactly one superclass.

A class (abstract or not) can implement multiple interfaces.

An interface can extends more than one interface.

WHAT ARE WE GOING TO DO TODAY?



- Comparable
- Iterable and Iterator

COMPARABLE

JAVA `Comparable` INTERFACE

- **The Java `Comparable` interface is used to define an ordering on objects of user-defined class.**
- **Why would you want that? Well, if you have a list of objects from a given class you might want to be able to sort it.**
- **`Comparable` is part of `java.lang` package and contains only one method named `compareTo(Object)`.**

JAVA Comparable INTERFACE

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

https://docs.oracle.com/javase/7/docs/api/java/lang/Comparable.html

JAVA `Comparable` INTERFACE

Some of the methods from certain Java classes use `compareTo()` in their implementation. To function correctly, they assume to be working with `Comparable` generic types. Examples:

- **`sort()` from `Arrays`.**

sort

```
public static void sort(Object[] a)
```

Sorts the specified array of objects into ascending order, according to the natural ordering of its elements. All elements in the array must implement the `Comparable` interface. Furthermore, all elements in the array must be *mutually comparable* (that is, `e1.compareTo(e2)` must not throw a `ClassCastException` for any elements `e1` and `e2` in the array).

JAVA `Comparable` INTERFACE

Some of the methods from certain Java classes use `compareTo()` in their implementation. To function correctly, they assume to be working with `Comparable` generic types. Examples:

- **`sort()` from `Collections`.**

sort

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

Sorts the specified list into ascending order, according to the natural ordering of its elements. All elements in the list must implement the `Comparable` interface. Furthermore, all elements in the list must be *mutually comparable* (that is, `e1.compareTo(e2)` must not throw a `ClassCastException` for any elements `e1` and `e2` in the list).

String IMPLEMENTS Comparable

compareTo

```
public int compareTo(String anotherString)
```

Compares two strings lexicographically. The comparison is based on the Unicode value of each character in the strings. The character sequence represented by this `String` object is compared lexicographically to the character sequence represented by the argument string. The result is a negative integer if this `String` object lexicographically precedes the argument string. The result is a positive integer if this `String` object lexicographically follows the argument string. The result is zero if the strings are equal; `compareTo` returns `0` exactly when the `equals(Object)` method would return `true`.

This is the definition of lexicographic ordering. If two strings are different, then either they have different characters at some index that is a valid index for both strings, or their lengths are different, or both. If they have different characters at one or more index positions, let *k* be the smallest such index; then the string whose character at position *k* has the smaller value, as determined by using the < operator, lexicographically precedes the other string. In this case, `compareTo` returns the difference of the two character values at position `k` in the two string -- that is, the value:

```
this.charAt(k)-anotherString.charAt(k)
```

If there is no index position at which they differ, then the shorter string lexicographically precedes the longer string. In this case, `compareTo` returns the difference of the lengths of the strings -- that is, the value:

```
this.length()-anotherString.length()
```

https://docs.oracle.com/javase/7/docs/api/java/lang/String.html

CLASSES THAT IMPLEMENT `Comparable`

- `Character`, `Integer`, `Float`, `Double`, `BigInteger`, **etc. all implement** `Comparable<T>`.

- **You cannot compare objects of these classes using the "<" operator. Instead use** `compareTo()`.

HOW TO IMPLEMENT `Comparable`

- **Add `implements Comparable` in the definition of the class.**

- **Implement `compareTo()` inside your class.**

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

REQUIREMENT FOR IMPLEMENTING `compareTo()`

Consider two variable `t1` and `t2` or type `T`. Then,

`t1.compareTo(t2)` **returns**

- **negative int** , if $t1 < t2$
- **0** , if $t1 = t2$
- **positive int** , if $t1 > t2$

The relation should also be anticommutative and transitive.

Highly recommended:

```
(t1.compareTo(t2)==0) == (t1.equals(t2))
```

EXAMPLE - CIRCLE

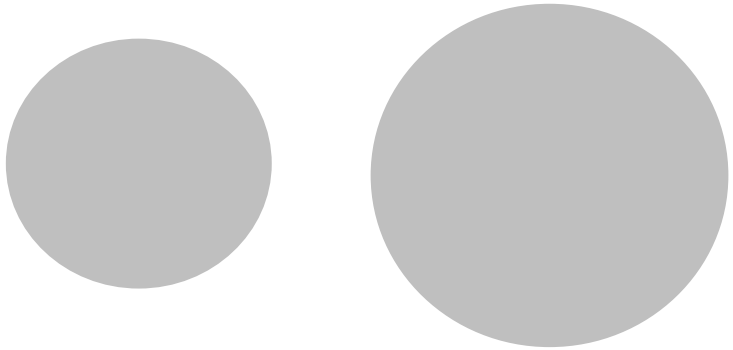
- Sometimes deciding how to compare elements of a given type can be straightforward.
- Let's think about the data type Circle.

```
public class Circle {
   private double radius;
   :
}
```

- How should we implement `compareTo()` and `equals()` in order to establish a *natural ordering* between elements of type `Circle`?

EXAMPLE - CIRCLE

- How should we implement `compareTo()` and `equals()` in order to establish a *natural ordering* between elements of type `Circle`?



We could simply compare their radius (or their area).

EXAMPLE – ORC

- Other times, is not so straightforward. Suppose we have created a new data type `Orc`.
- How should we compare and sort elements of this type?

Base on their name? On their height? On their weapon? On who is scarier?

ORC – compareTo() TAKE 1

```
public class Orc implements Comparable<Orc> {
   private String name;
   private int height;
   private Weapon w;
   public int compareTo(Orc o) {
      if(this.height < o.height) {
         return -1;
      } else if(this.height == o.height) {
         return 0;
      }  else {
         return 1;
      }
   }
}
```

- Note that in this case we probably don't want to consider two Orcs with the same weight to be equal.
- This implies that the implementation of compareTo() violates the Java API recommendations.
- Such violation should be clearly indicated using the following language: "Note: this class has a natural ordering that is inconsistent with equals."

ORC – compareTo() TAKE 2

```
public class Orc implements Comparable<Orc> {
    private String name;
    private int height;
    private Weapon w;
    public int compareTo(Orc o) {
        int result = this.w.compareTo(o.w);
        if(result==0) {
            result = Integer.compare(this.weight, o.weight);
        }
        if(result == 0) {
            result = this.name.compareTo(o.name);
        }
        return result;
    }
}
```

- We can also use compareTo() to compare multiple characteristics.
- Generally, it is better to reuse existing code than to write our own. Thus, in this case, we can use the *compareTo()* methods from other classes to.

TO RECAP

- Comparable defines a natural ordering.

- If you define a new data type for which sorting makes sense to you, then you should implement comparable to define a natural ordering on objects of such type.

ITERABLE and ITERATOR

REMEMBER THE FOR-EACH LOOP?

```
int[] numbers = {1,2,3,4,5};
for(int element: numbers) {
   System.out.println(element);
}
```

The for-each loop (also called enhanced for loop) can make your code more readable and can be convenient to use. It is not helpful when you need to refer to the index of an element. For certain data structures is the only loop we can use…

ITERABLE AND ITERATOR

- The use of a *for-each* loop is made possible by the use of two interfaces: `Iterator` and `Iterable`.

- For beginners, the two interfaces are often confusing. Even though they are similar, they refer to two different things:
  - Objects of type `Iterable` are representations of a series of elements that can be iterated over. (e.g. a specific `ArrayList`)
  - Objects of type `Iterator` allows you to iterate through objects that represent a collection (a series of elements).

JAVA ITERABLE INTERFACE

```
public interface Iterable<T> {
  public Iterator<T> iterator();
}
```

```
public interface Iterator<T> {
   boolean hasNext();
   T next();   // returns current,
               // and advances to next
   void remove(); // optional, ignore it
}
```

- A class that implements `Iterable` needs to implement the `iterator()` method. The `iterator()` method returns an object of type `Iterator` that can then be used to iterate through the elements of the object to that class.

- A class that implements `Iterator` needs to implement the methods `hasNext()` and `next()`.

OBSERVATION

```
public interface Iterable<T> {
  public Iterator<T> iterator();
}
```

```
public interface Iterator<T> {
   boolean hasNext();
   T next();   // returns current,
               // and advances to next
   void remove(); // optional, ignore it
}
```

- **The `iterator()` method returns an iterator to the start of the collection. Using `hasNext()` and `next()` you can move forward in the collection. If you want to traverse the collection again, you'll need a new `Iterator`.**

ITERABLE AND FOR-EACH LOOP

- Implementing the Iterable interface allows an object to make use of the for-each loop. It does that by internally calling the iterator() method on the object!

HOW TO IMPLEMENT THE INTERFACES

- As always when implementing interfaces, a class that implements an interface must implement every method from such interface.
- Generally, when we write a class that implements the interface `Iterable` we also write a class that implements the interface `Iterator`. Often, such class is defined as an inner class of the first class.
- Why? To implement `Iterable`, we need to implement the method `iterator()`. Such method need to return an object of type `Iterator` that can iterate through the elements of a specific object of the outer class. We need a class that can create such object.

EXAMPLE

```
public class MyCollection<T> implements Iterable<T> {
    public MyIterator<T> iterator() {
        return new MyIterator<T>(this);
    }
}
```

```
public class MyIterator<E> implements Iterator<E> {
    public MyIterator(MyCollection<E> c) {
        :
    }
}
```

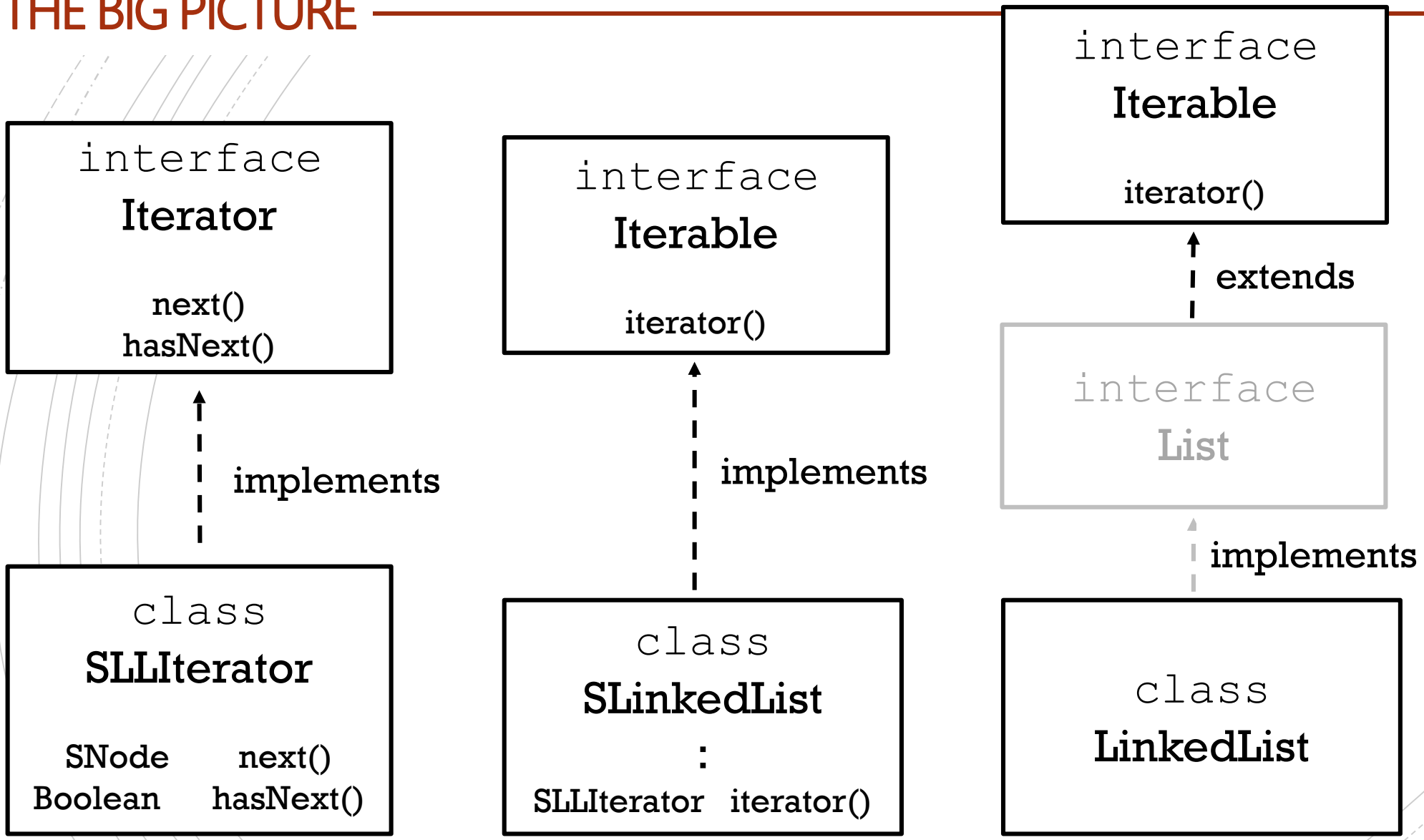
- **In general, if the class `MyIterator` is used only by the class `MyCollection`, good practice is to make that class a private inner class of `MyCollection`.**

FROM A2

- `iterator()` **returns an object of type** `Iterator` **that points to the head of the provided list.**
- `next()` **returns the element of the list that the** `Iterator` **is currently referencing, and then moves to the next node.**

```
public class SLinkedList<E> implements Iterable<E> {
    private SNode<E> head;
    public SLLIterator iterator() {
        return new SLLIterator(this);
    }
    private class SLLIterator implements Iterator<E> {
        SNode<E> cur;
        SLLIterator(SLinkedList<E>  list) {
            cur = list.head;
        }
        public boolean hasNext() {
            return (cur != null);
        }
        public E next() {
            SNode<E> tmp = cur;
            cur = cur.next;
            return tmp.element;
        }
    }
}
```

THE BIG PICTURE



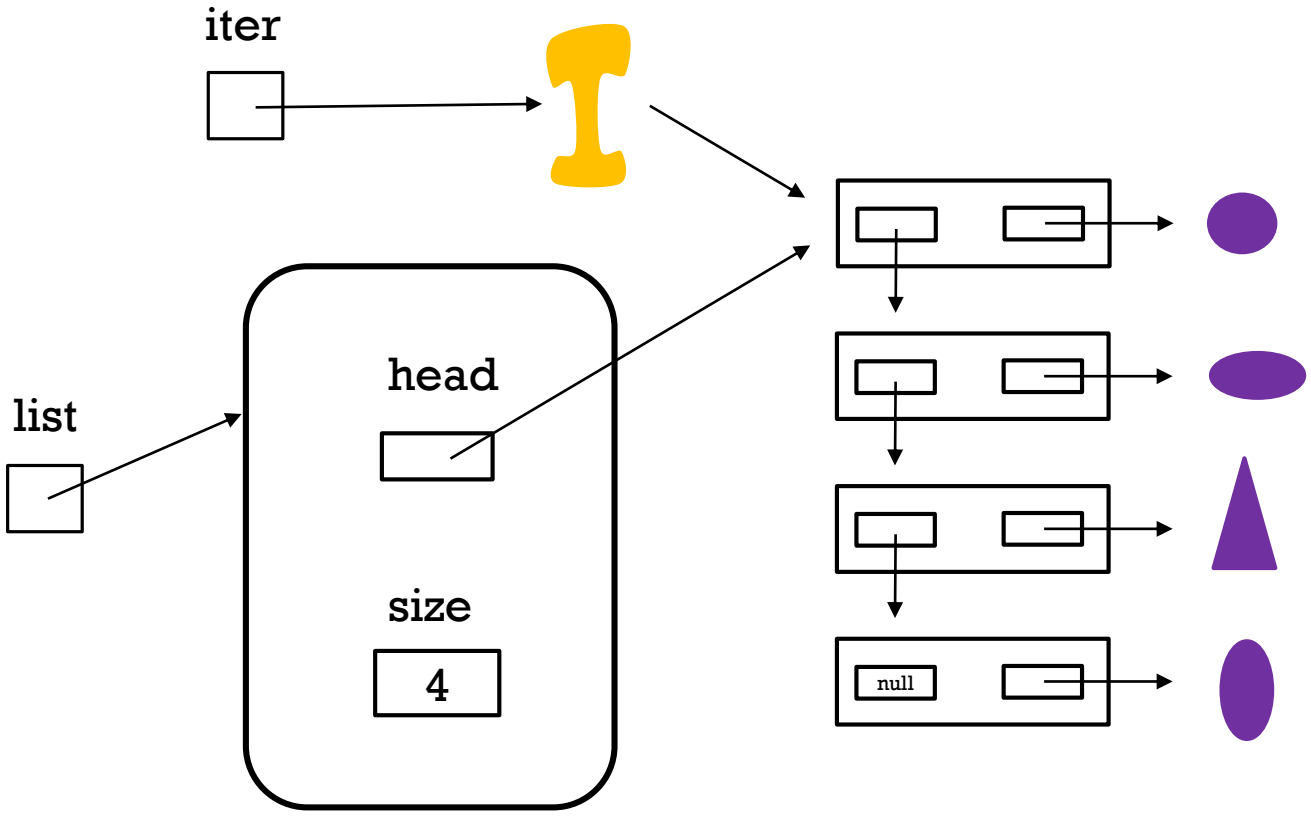
EXAMPLE

- Suppose we have a SLinkedList of Shapes:

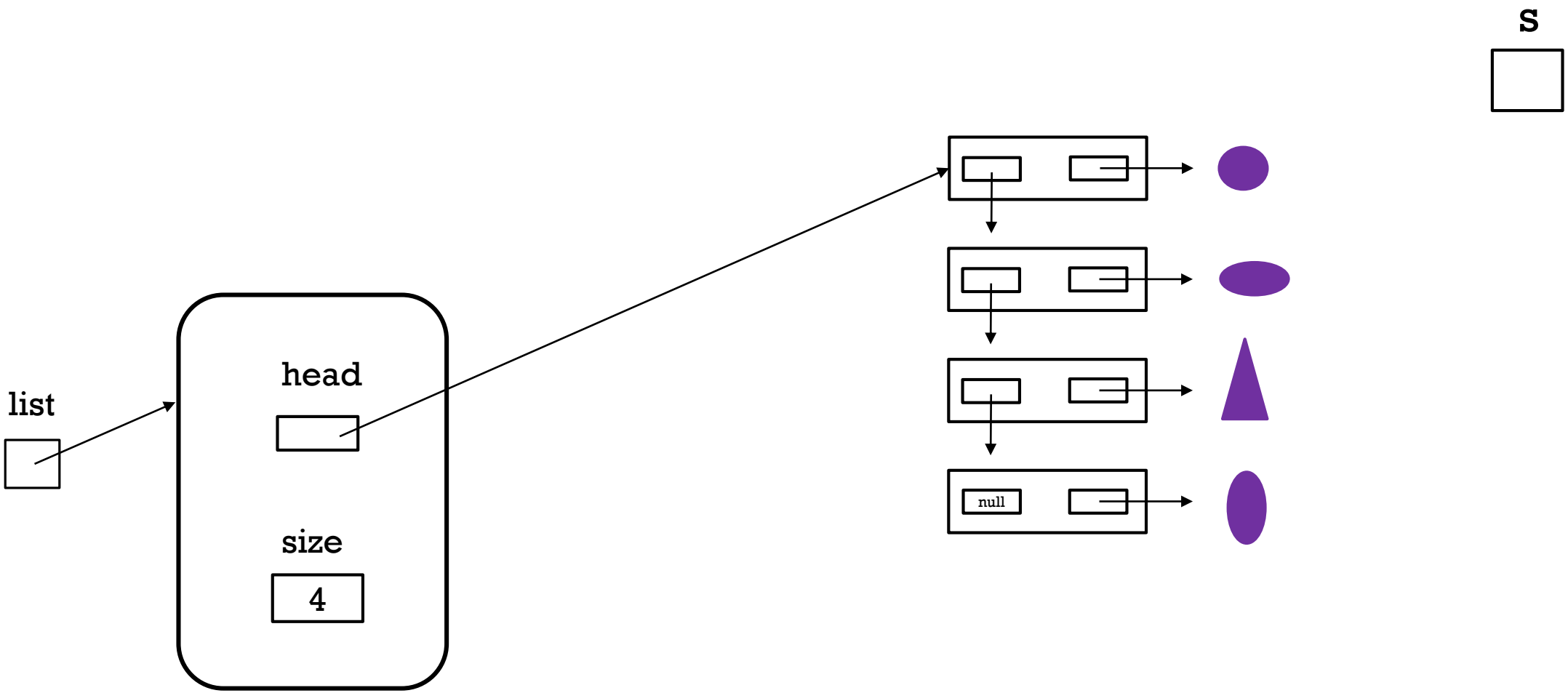
```
SLinkedList<Shape> list = …
```

- Then by calling iterator() we create an object of type SLLIterator that points to the head of the list.

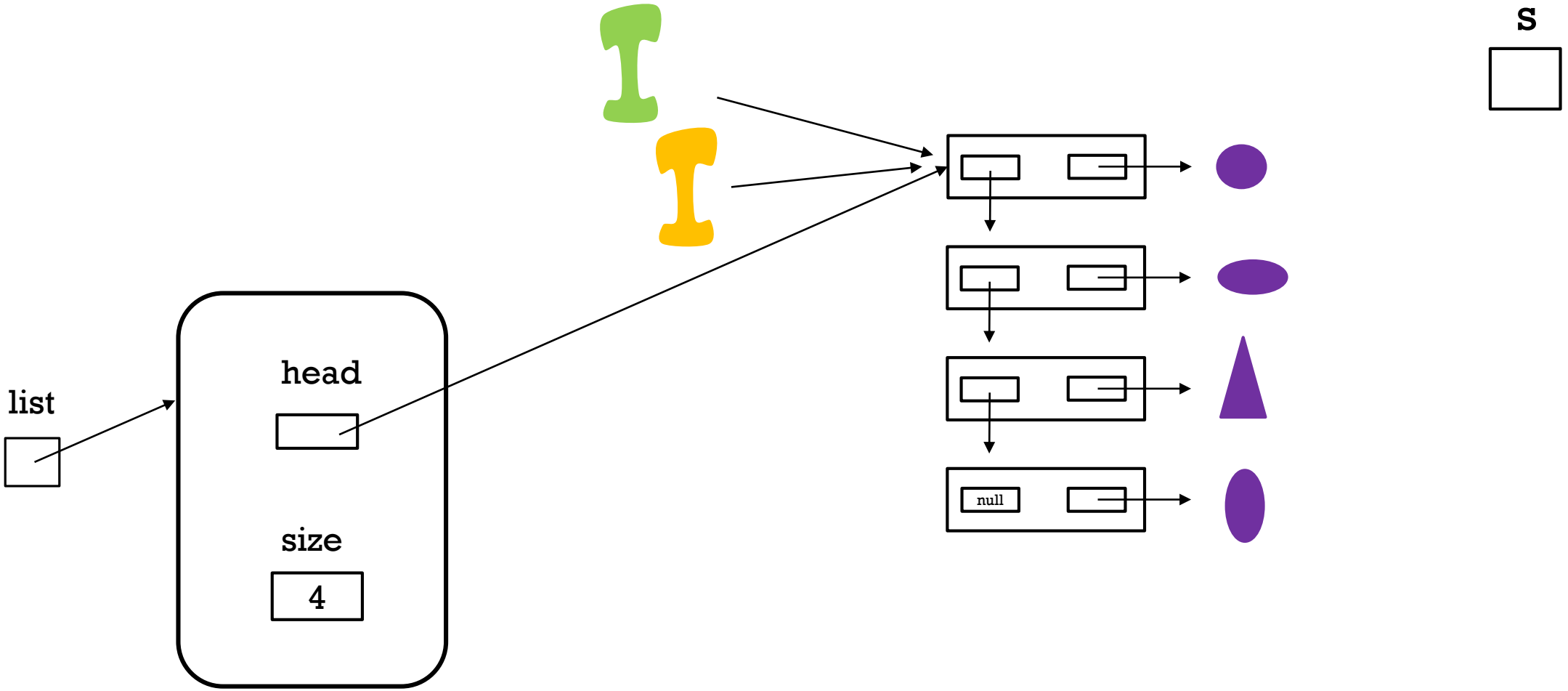
```
SLLIterato iter =
list.iterator();
```



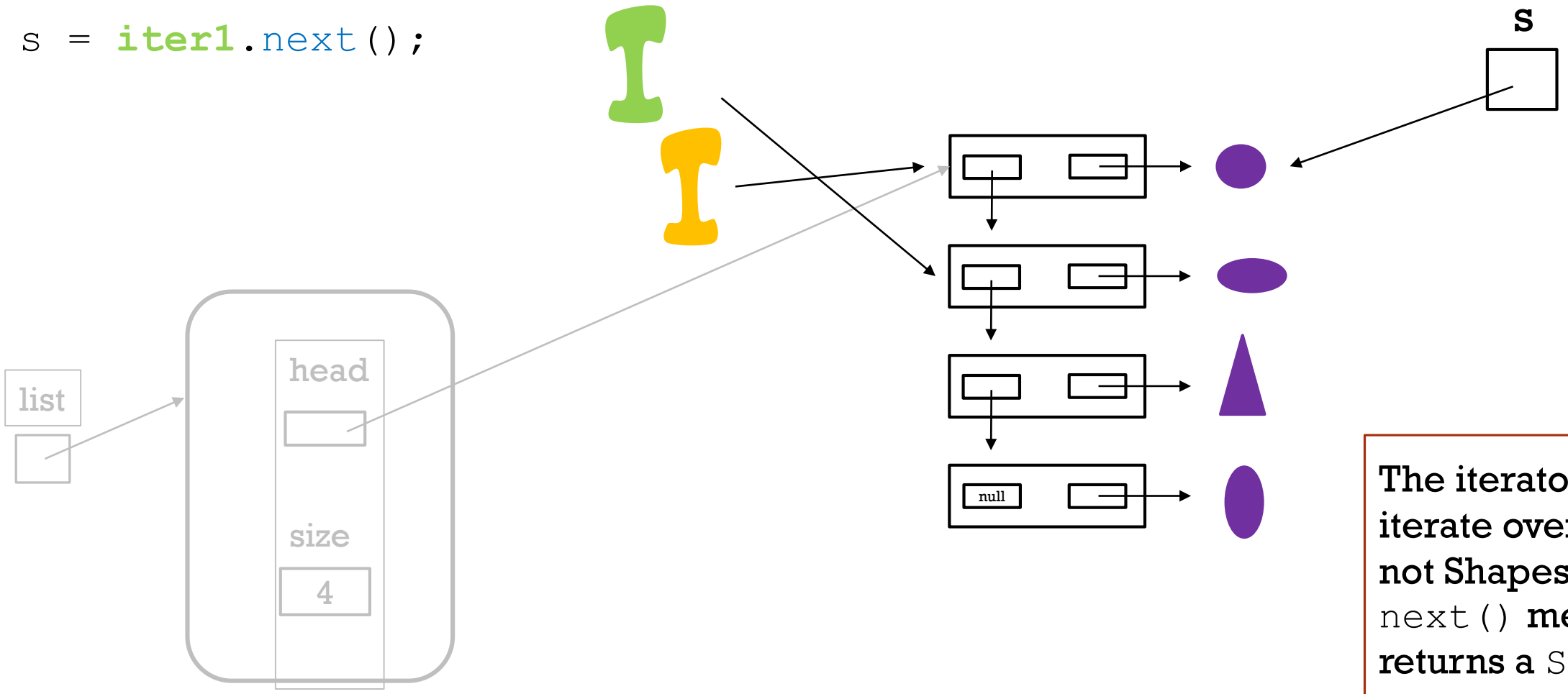
```
LinkedList<Shape>   list = … ;
Shape   s;
```



```
LinkedList<Shape> list = … ;
Shape s;
Iterator<Shape> iter1 = list.iterator();
Iterator<Shape> iter2 = list.iterator();
```

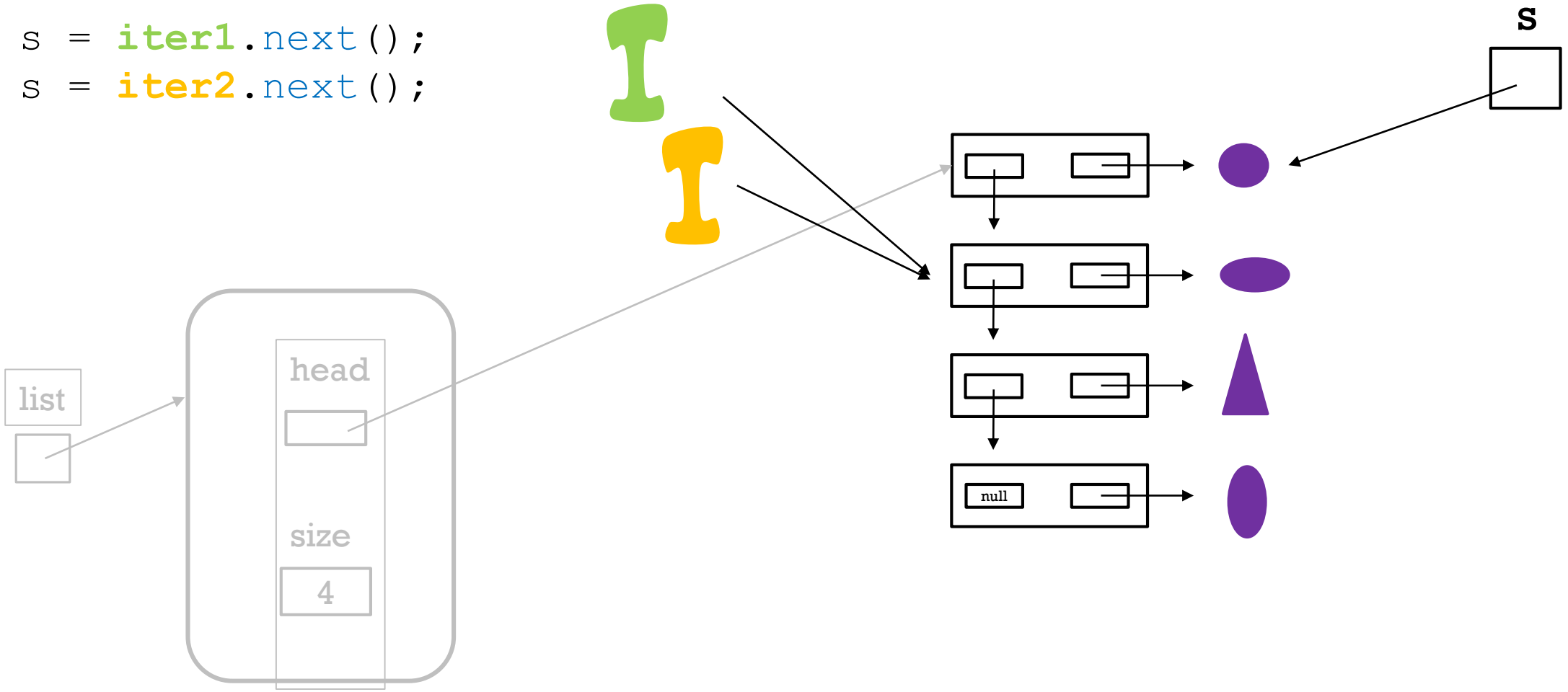


```
LinkedList<Shape> list = … ;
Shape s;
Iterator<Shape> iter1 = list.iterator();
Iterator<Shape> iter2 = list.iterator();

s = iter1.next();
```

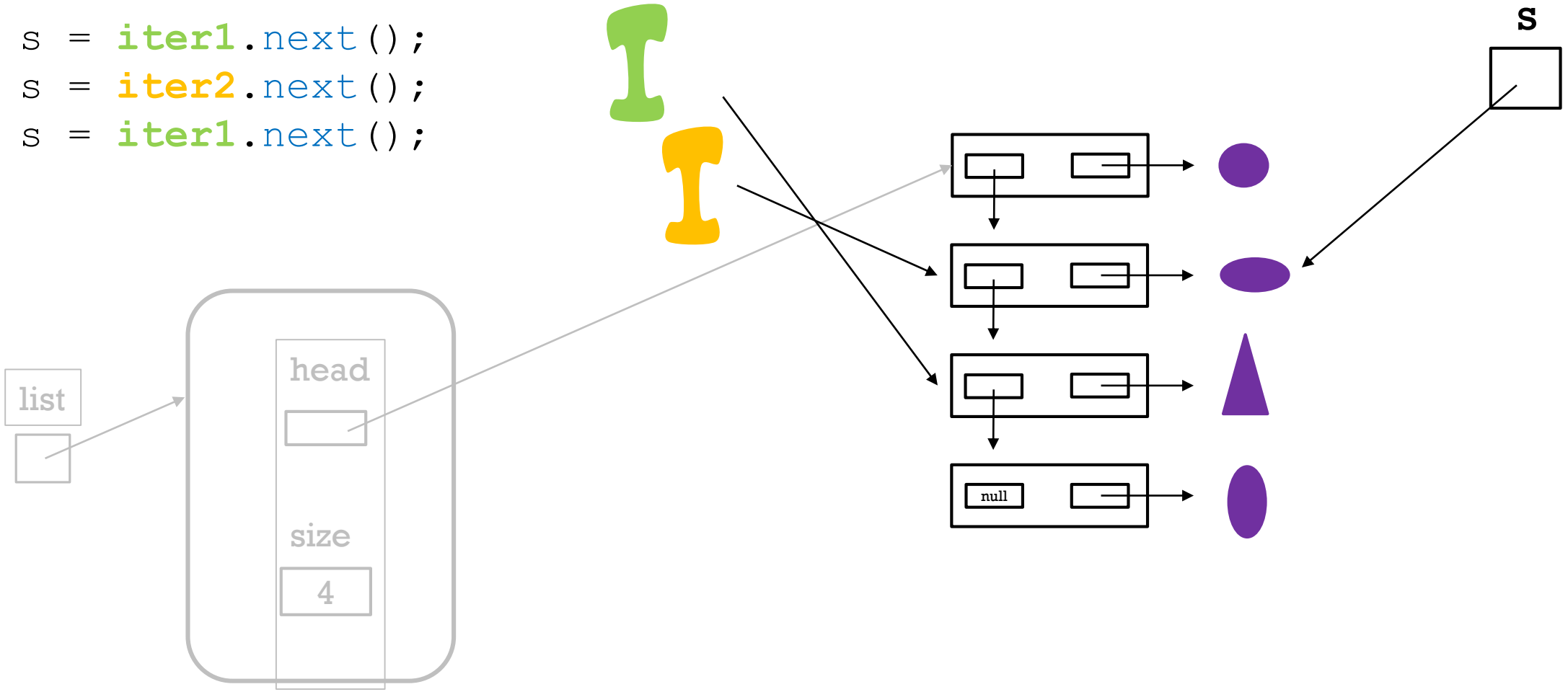


The iterators iterate over nodes, not Shapes. The `next()` method returns a `Shape`.

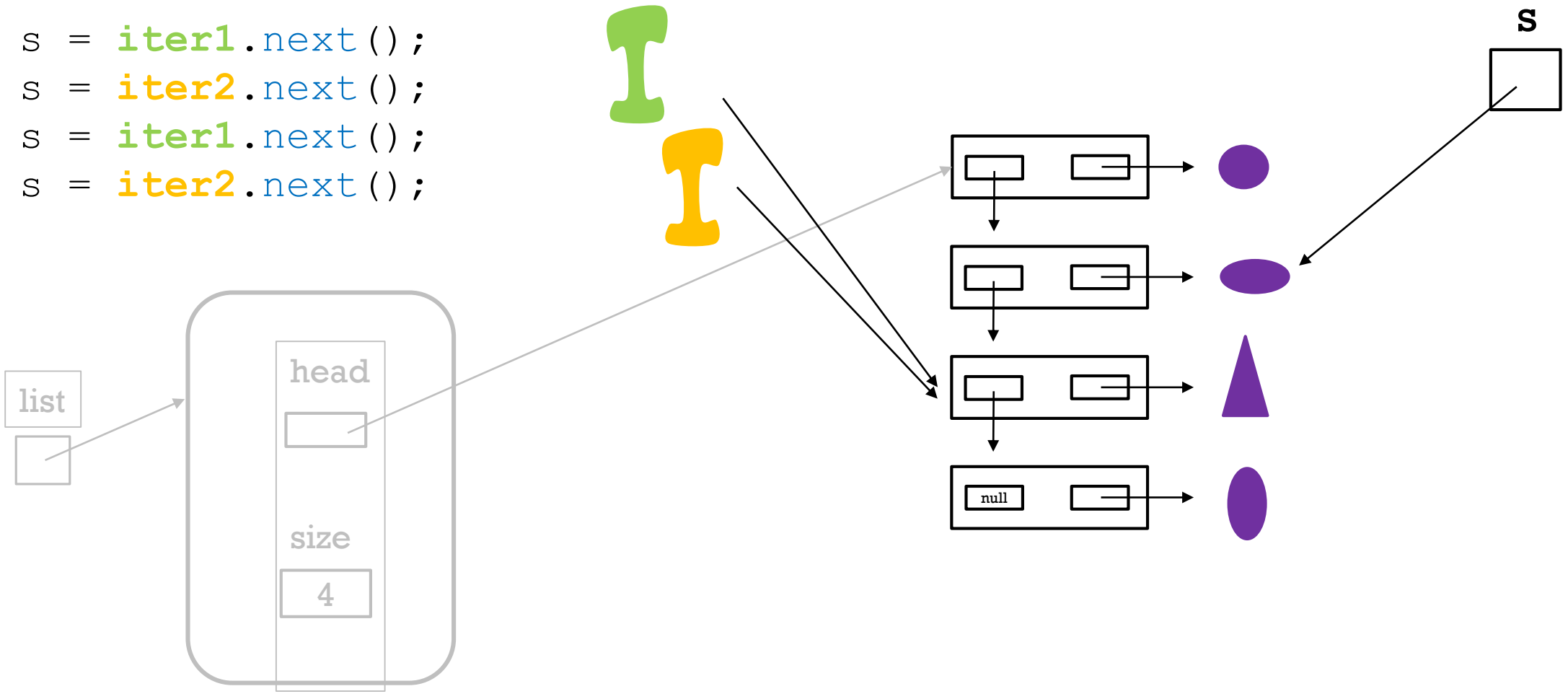
```
LinkedList<Shape> list = … ;
Shape s;
Iterator<Shape> iter1 = list.iterator();
Iterator<Shape> iter2 = list.iterator();

s = iter1.next();
s = iter2.next();
```



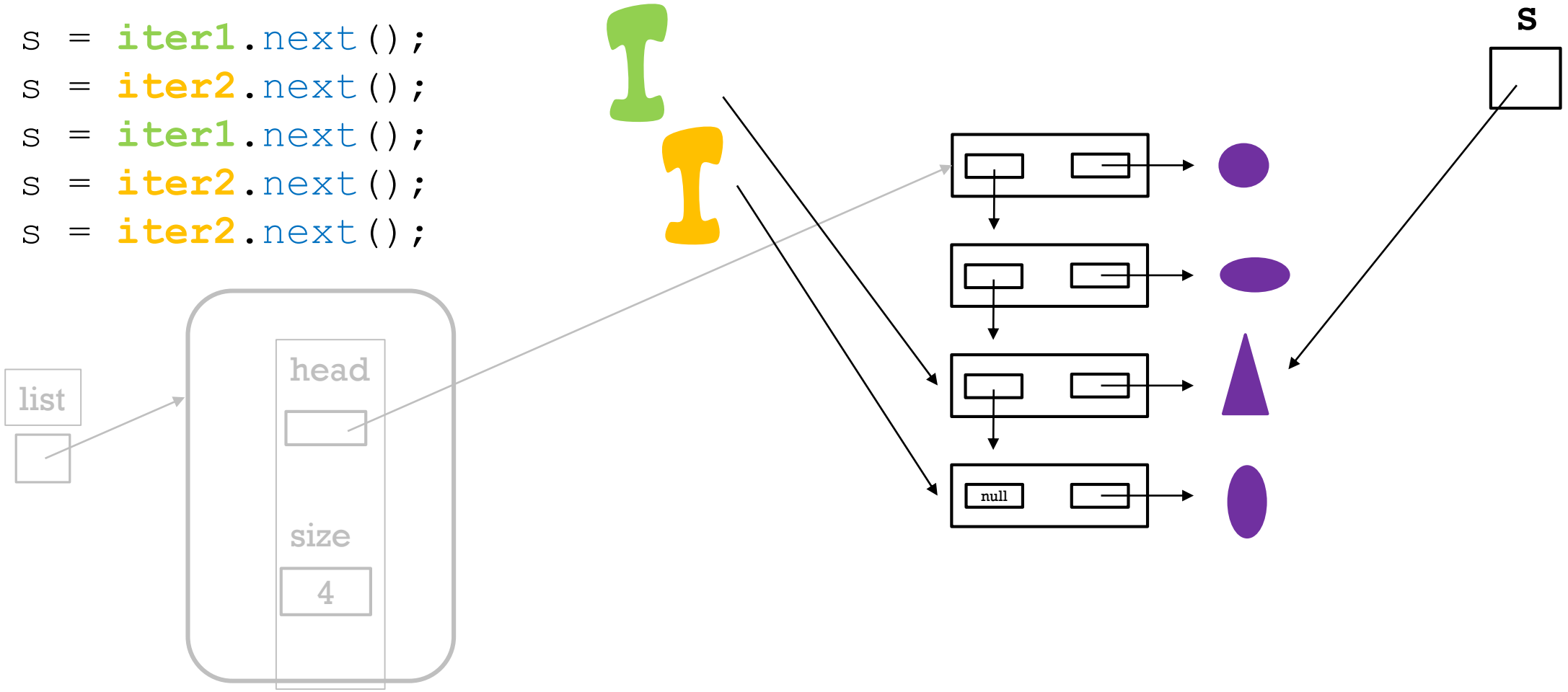
```
LinkedList<Shape> list = … ;
Shape s;
Iterator<Shape> iter1 = list.iterator();
Iterator<Shape> iter2 = list.iterator();

s = iter1.next();
s = iter2.next();
s = iter1.next();
```



```
LinkedList<Shape> list = … ;
Shape s;
Iterator<Shape> iter1 = list.iterator();
Iterator<Shape> iter2 = list.iterator();

s = iter1.next();
s = iter2.next();
s = iter1.next();
s = iter2.next();
```



```
LinkedList<Shape> list = … ;
Shape s;
Iterator<Shape> iter1 = list.iterator();
Iterator<Shape> iter2 = list.iterator();

s = iter1.next();
s = iter2.next();
s = iter1.next();
s = iter2.next();
s = iter2.next();
```



- Memory allocation
- The class Class
- Garbage collection (maybe)