Generics (Templates)

CSE 017 | Prof Ziltz | Spring 23

Today's Plan

- What are generics?
- Using generic classes (`ArrayList`) and generic methods (`sort`)
- Creating new generic classes with one type parameter or more
- Creating generic methods
- Restrictions on generic type

Student Learning Outcomes

By the end of this week, you should be able to:

- Use generic classes, generic interfaces, and generic methods from the Java API
- Implement your own generic classes and generic methods

Generics

- **Generics allow to specify a range of types allowable for a class, an interface, or a method**
    - Definition not limited to a single/specific type
- **Used to create classes that hold data of different types**
- **Used to create methods that accept parameters of different types**
- **Example:** Comparable<E> Interface (defined in java.util)

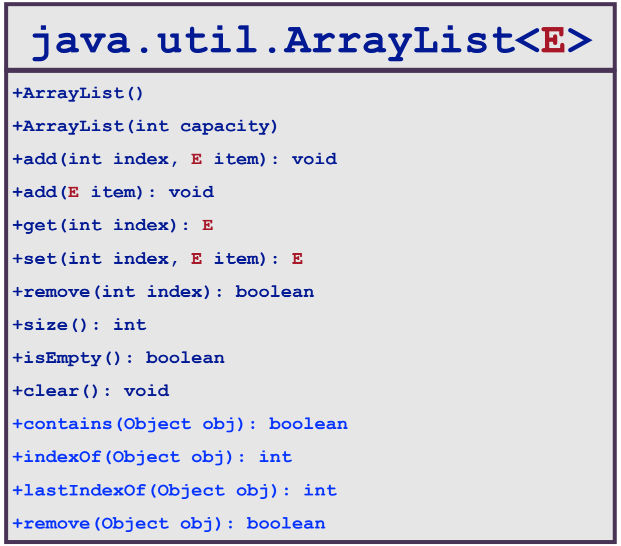
```
interface Comparable<E> {
  int compareTo(E obj);
}
```

Using Generic Classes/Interfaces

- Generic Class – Class of type `<E>`
- `E` is the type parameter or generic type
- `E` can be replaced by any reference type String, Integer, or Student
- Primitive types are not allowed as generic type parameters (int, double, char, …)
  - This is why we care about wrapper classes ˆ
- Can use any name for the generic type (between <>) but the convention is <E> or <T>

Generic Class Ex: `java.util.ArrayList;`

- Array of objects of any type
- Array of any size
- The size of the array may increase or decrease at runtime
- Like a Wrapper class for Arrays
- *Who's used/seen before?*



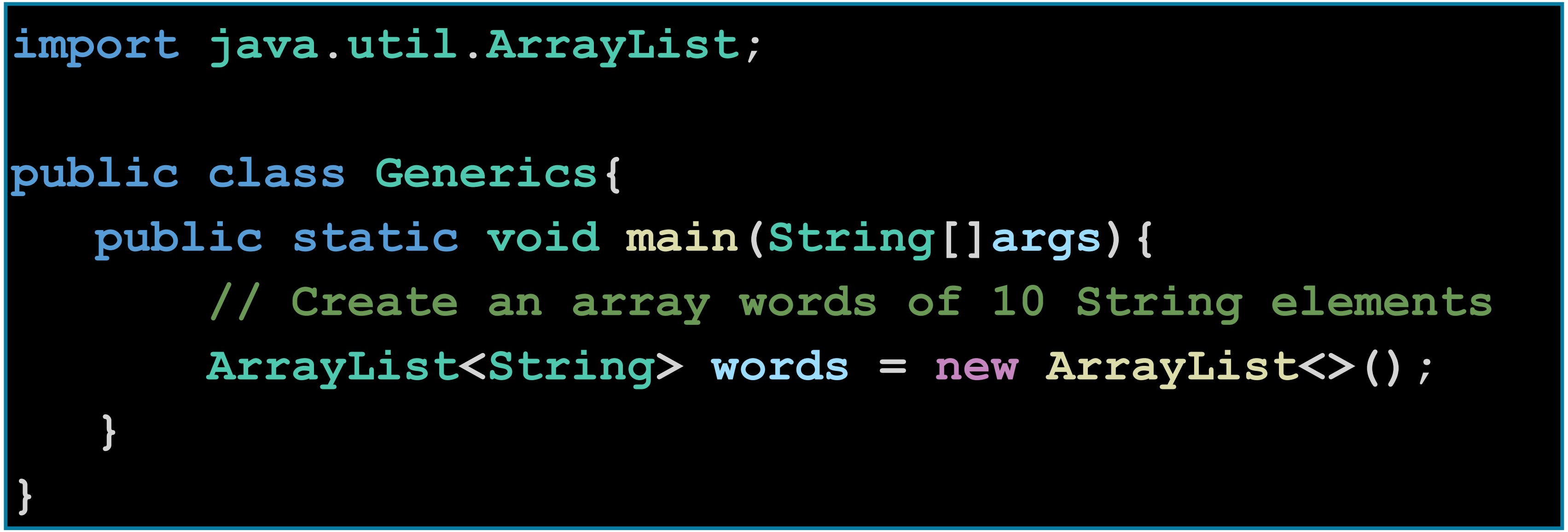
```
java.util.ArrayList<E>

+ArrayList()
+ArrayList(int capacity)
+add(int index, E item): void
+add(E item): void
+get(int index): E
+set(int index, E item): E
+remove(int index): boolean
+size(): int
+isEmpty(): boolean
+clear(): void
+contains(Object obj): boolean
+indexOf(Object obj): int
+lastIndexOf(Object obj): int
+remove(Object obj): boolean
```

Generic Class Ex: `java.util.ArrayList;`

```
+ArrayList()
+ArrayList(int capacity)
+add(int index, E item): void
+add(E item): void
+get(int index): E
+set(int index, E item): E
+remove(int index): boolean
+size(): int
+isEmpty(): boolean
+clear(): void
+contains(Object obj): boolean
+indexOf(Object obj): int
+lastIndexOf(Object obj): int
+remove(Object obj): boolean
+remove(int index): boolean
```

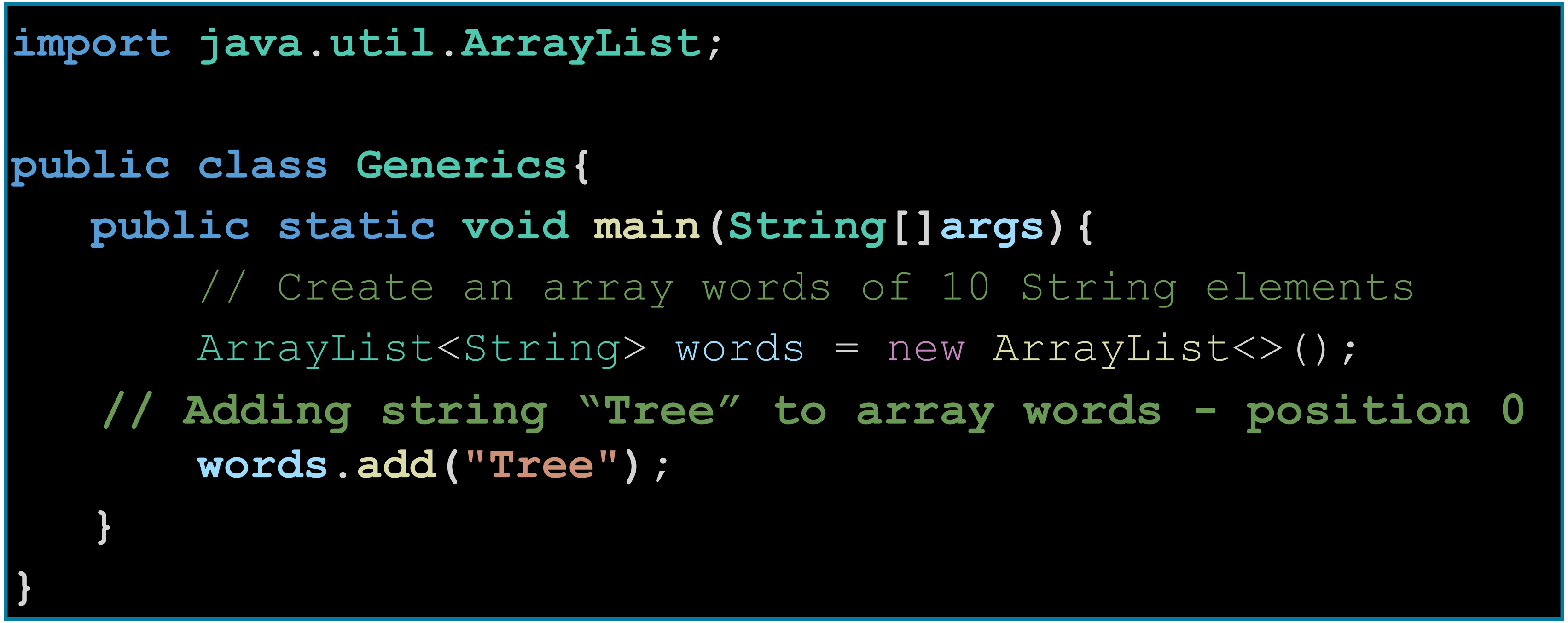
- 2 Constructors:
  - no-arg creates an array of default size 10
  - One-arg creates an array of size `capacity`
- add (overloaded)
  - **`add(int index, E item)`**: adds `item` at location `index`.
    - All elements from `index` to `size()-1` are pushed one position up
  - **`add(E item)`**: adds `item` at first open location
- **`get(int index)`**: returns `item` at `index`
- **`set(int index, E item)`**: replaces element at location `index` with `item`
  - returns the old value of the `item` at `index`
- **`remove(int index): boolean`**
- **`size()`**: returns the actual size of the array (not `capacity`)
- **`isEmpty()`**: returns true if the array is empty
- **`clear()`**: reset size to 0
- **`contains(Object obj)`**: returns true if `obj` is in the array
- **`indexOf(Object obj)`**: returns the first index of `obj` if found, -1 otherwise
- **`lastIndexOf(Object obj)`**: returns the last index of `obj` if found, -1 otherwise
- Remove (overloaded):
  - **`remove(Object obj)`**: Returns true if `obj` is removed, and false otherwise
  - **`remove(int index)`**: Returns true if `index` is valid and element at `index` removed, false otherwise

Using an ArrayList <String>



```java
import java.util.ArrayList;

public class Generics{
    public static void main(String[]args){
        // Create an array words of 10 String elements
        ArrayList<String> words = new ArrayList<>();
    }
}
```

Adding to an ArrayList <String>

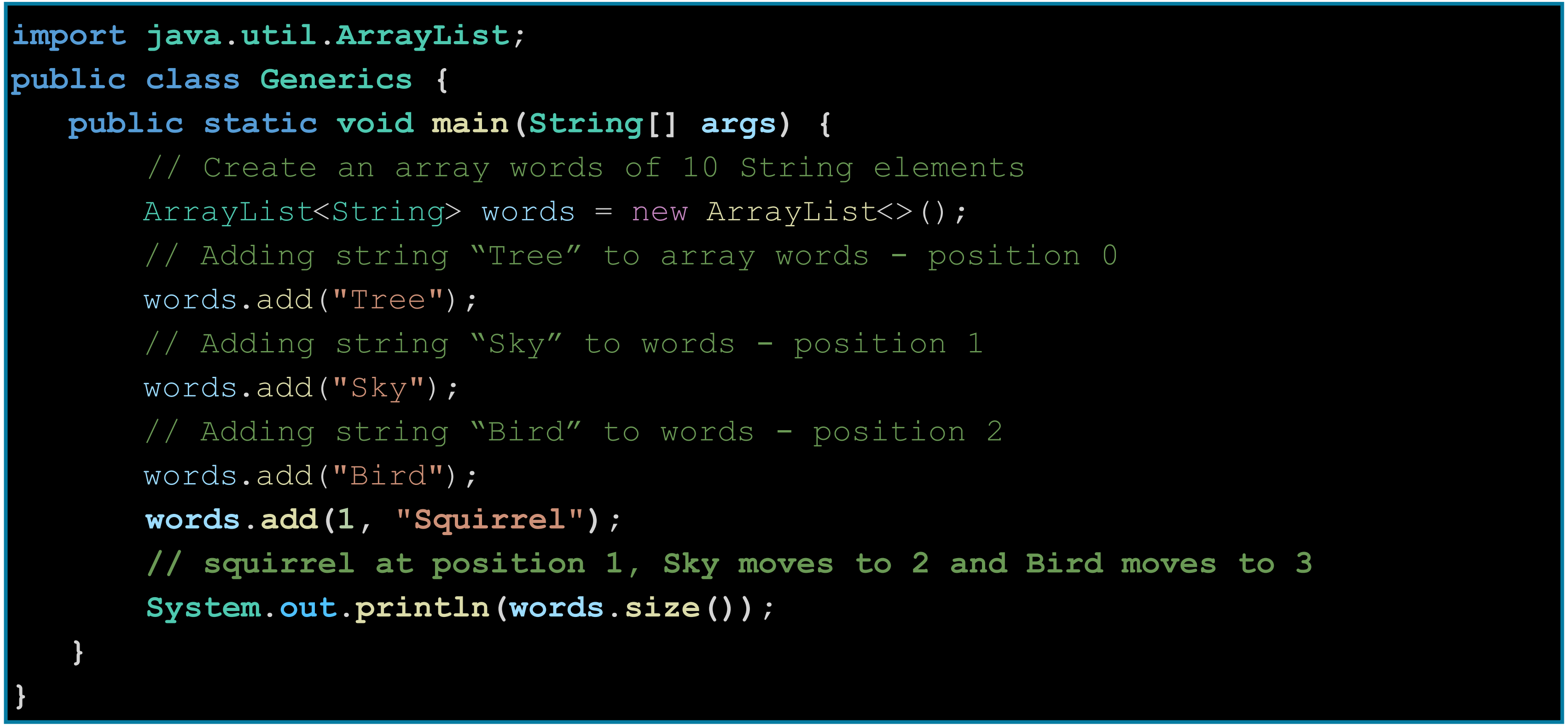


```
import java.util.ArrayList;

public class Generics{
   public static void main(String[]args){
       // Create an array words of 10 String elements
       ArrayList<String> words = new ArrayList<>();
   // Adding string “Tree” to array words - position 0
       words.add("Tree");
   }
}
```

Adding to an ArrayList <String>

```
import java.util.ArrayList;
public class Generics {
    public static void main(String[] args) {
         // Create an array words of 10 String elements
         ArrayList<String> words = new ArrayList<>();
         // Adding string “Tree” to array words - position 0
         words.add("Tree");
         // Adding string “Sky” to words - position 1
         words.add("Sky");
         // Adding string “Bird” to words - position 2
         words.add("Bird");
    }
}
```

Adding to an `ArrayList <String>`

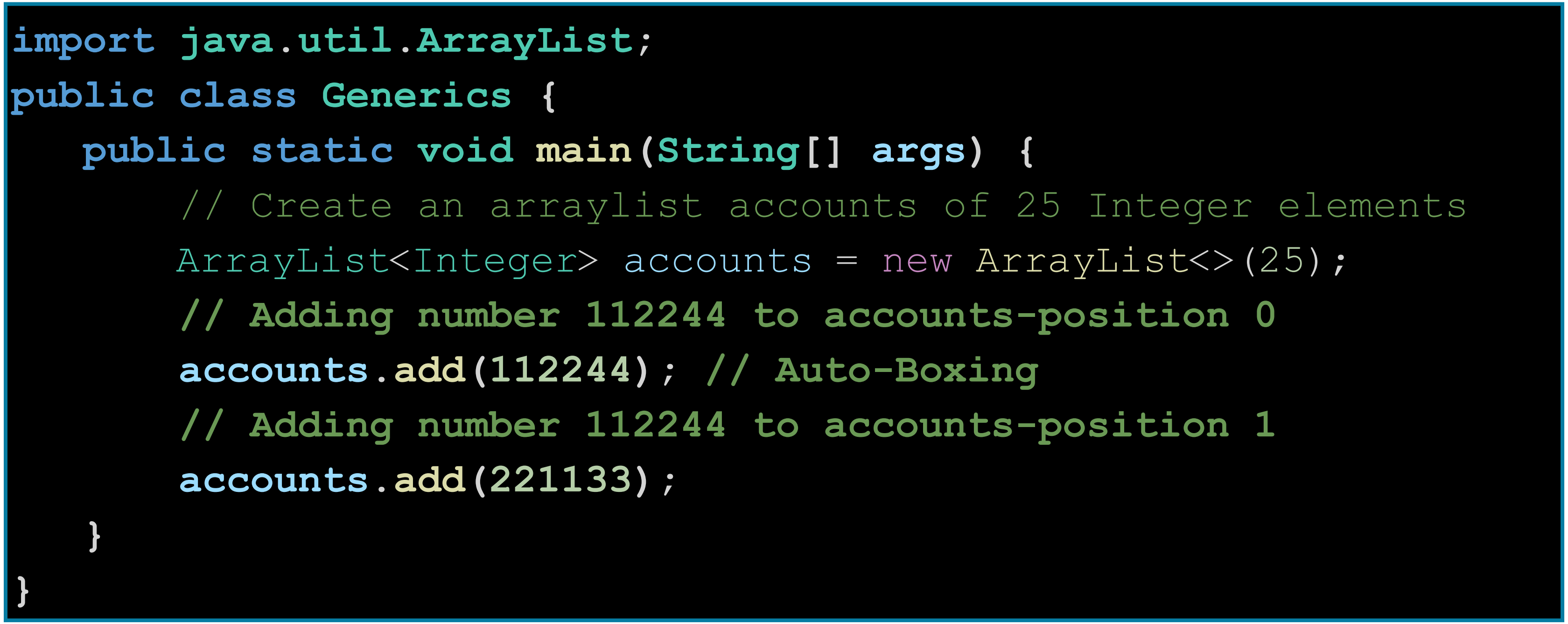


```java
import java.util.ArrayList;
public class Generics {
   public static void main(String[] args) {
       // Create an array words of 10 String elements
       ArrayList<String> words = new ArrayList<>();
       // Adding string “Tree” to array words - position 0
       words.add("Tree");
       // Adding string “Sky” to words - position 1
       words.add("Sky");
       // Adding string “Bird” to words - position 2
       words.add("Bird");
       words.add(1, "Squirrel");
       // squirrel at position 1, Sky moves to 2 and Bird moves to 3
       System.out.println(words.size());
   }
}
```

Using an ArrayList <Integer>

```
import java.util.ArrayList;

public class Generics {
   public static void main(String[] args) {
       //Create an arraylist accounts of 25 Integer elements
       ArrayList<Integer> accounts = new ArrayList<>(25);


   }
}
```

Adding to an ArrayList <Integer>



```java
import java.util.ArrayList;
public class Generics {
    public static void main(String[] args) {
        // Create an arraylist accounts of 25 Integer elements
        ArrayList<Integer> accounts = new ArrayList<>(25);
        // Adding number 112244 to accounts-position 0
        accounts.add(112244); // Auto-Boxing
        // Adding number 112244 to accounts-position 1
        accounts.add(221133);
    }
}
```

Accessing an ArrayList <Integer>

```java
import java.util.ArrayList;
public class Generics {
    public static void main(String[] args) {
        // Create an arraylist accounts of 25 Integer elements
        ArrayList<Integer> accounts = new ArrayList<>(25);
        // Adding number 112244 to accounts-position 0
        accounts.add(112244); // Auto-Boxing
        // Adding number 112244 to accounts-position 1
        accounts.add(221133);
        int account = accounts.get(1); // Auto-Unboxing
        System.out.println(accounts.size()); // 2
    }
}
```

Printing an ArrayList <Integer>

```
import java.util.ArrayList;
public class Generics {
  public static void main(String[] args) {
       // Create an arraylist accounts of 25 Integer elements
       ArrayList<Integer> accounts = new ArrayList<>(25);
       // Adding number 112244 to accounts-position 0
       accounts.add(112244); // Auto-Boxing
       // Adding number 112244 to accounts-position 1
       accounts.add(221133);
       int account = accounts.get(1); // Auto-Unboxing
       System.out.println(accounts.size()); // 2
       for(Integer item: accounts){
            System.out.println(item);
         }
   }
}
```

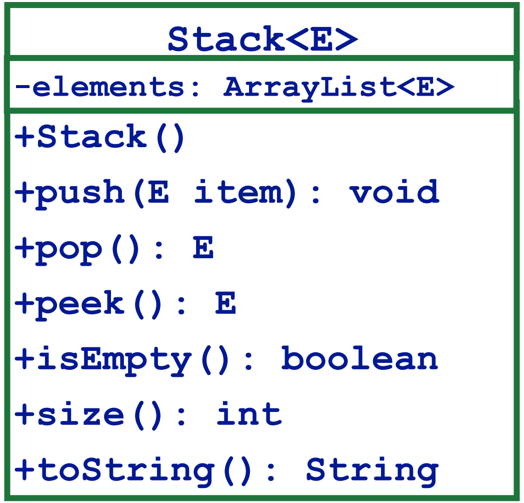
Common Error w/ `ArrayList:` Primitive Types

```java
import java.util.ArrayList;

public class Generics {
    public static void main(String[] args) {
        // Create numbers with 10 int elements
        // Error
        ArrayList<int> numbers = new ArrayList<>();
    }
}
```

Quick Summary: What are generics?

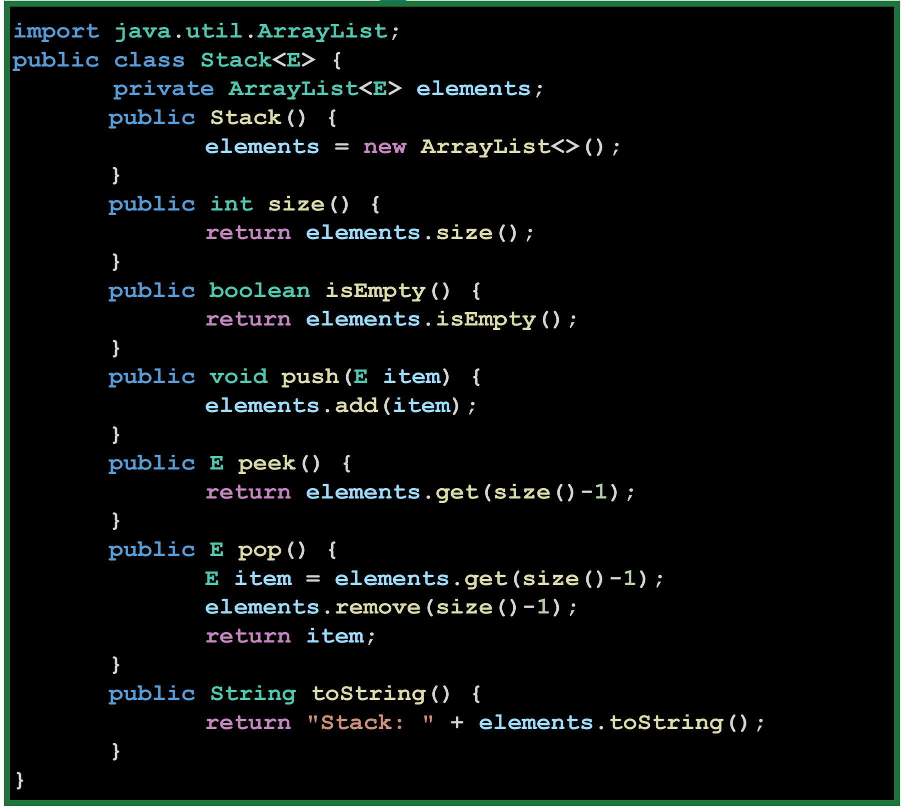
- A generic type can be defined for a class or an interface
- A concrete type must be specified when using the generic class/interface
- Either to create objects or use the class as a reference type

Creating Generic Classes

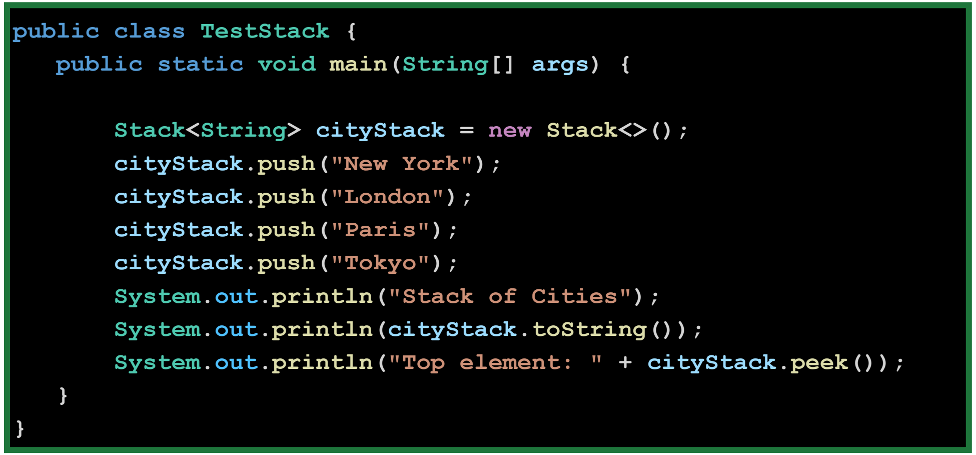


```
Stack<E>
-elements: ArrayList<E>
+Stack()
+push(E item): void
+pop(): E
+peek(): E
+isEmpty(): boolean
+size(): int
+toString(): String
```

Creating a Generic Class: Stack <E>

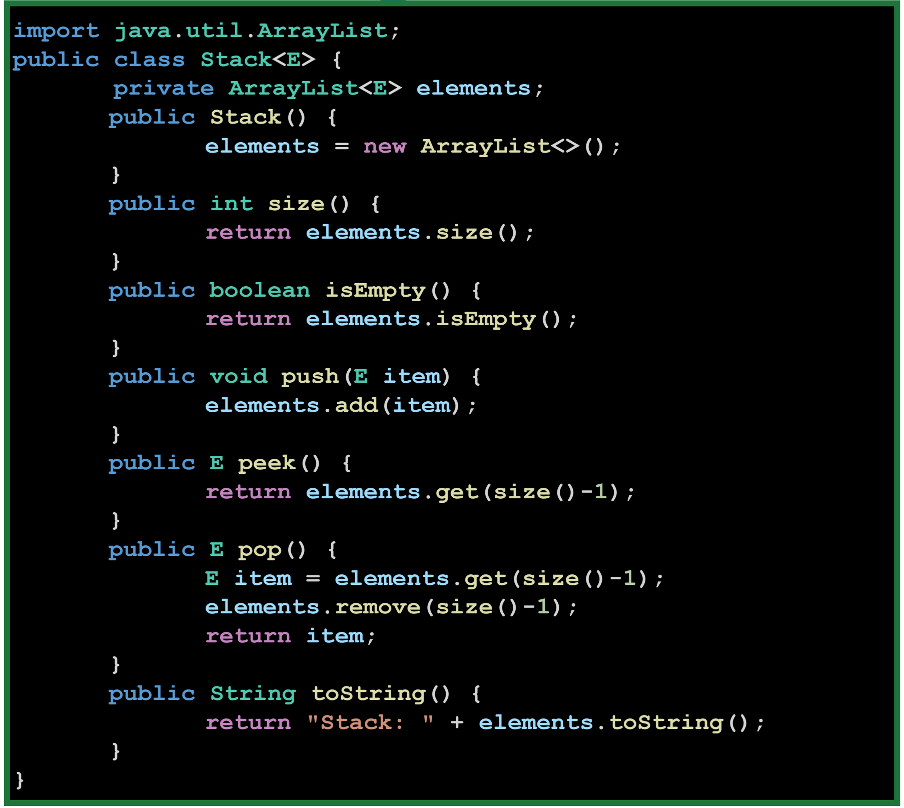


```java
import java.util.ArrayList;
public class Stack<E> {
        private ArrayList<E> elements;
        public Stack() {
                elements = new ArrayList<>();
        }
        public int size() {
                return elements.size();
        }
        public boolean isEmpty() {
                return elements.isEmpty();
        }
        public void push(E item) {
                elements.add(item);
        }
        public E peek() {
                return elements.get(size()-1);
        }
        public E pop() {
                E item = elements.get(size()-1);
                elements.remove(size()-1);
                return item;
        }
        public String toString() {
                return "Stack: " + elements.toString();
        }
}
```

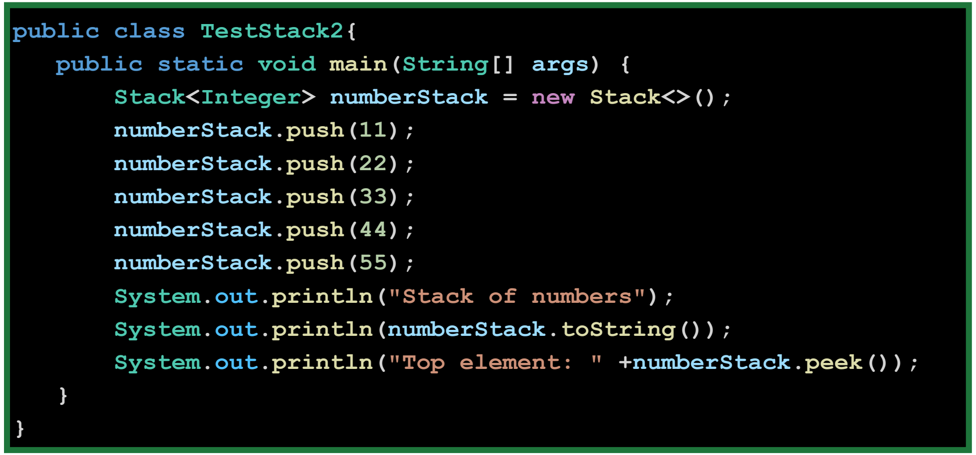


```java
public class TestStack {
    public static void main(String[] args) {

        Stack<String> cityStack = new Stack<>();
        cityStack.push("New York");
        cityStack.push("London");
        cityStack.push("Paris");
        cityStack.push("Tokyo");
        System.out.println("Stack of Cities");
        System.out.println(cityStack.toString());
        System.out.println("Top element: " + cityStack.peek());
    }
}
```

Creating a Generic Class: Stack <E>



```
import java.util.ArrayList;
public class Stack<E> {
       private ArrayList<E> elements;
       public Stack() {
              elements = new ArrayList<>();
       }
       public int size() {
              return elements.size();
       }
       public boolean isEmpty() {
              return elements.isEmpty();
       }
       public void push(E item) {
              elements.add(item);
       }
       public E peek() {
              return elements.get(size()-1);
       }
       public E pop() {
              E item = elements.get(size()-1);
              elements.remove(size()-1);
              return item;
       }
       public String toString() {
              return "Stack: " + elements.toString();
       }
}
```



```
public class TestStack2{
   public static void main(String[] args) {
       Stack<Integer> numberStack = new Stack<>();
       numberStack.push(11);
       numberStack.push(22);
       numberStack.push(33);
       numberStack.push(44);
       numberStack.push(55);
       System.out.println("Stack of numbers");
       System.out.println(numberStack.toString());
       System.out.println("Top element: " +numberStack.peek());
   }
}
```

Implementing Generics

- **After compile time, `E` is removed and replaced with the raw type (`Object`)**
  - Erasure of the generic type
- **Old way of implementing generics: use type `Object` instead of `E`**
  - Using array with elements of type `Object` would also work
- **Using Generics improves software reliability and readability**
- **Errors are detected at compile time**
  - This is why we use `E` (a concrete type) rather than `Object` (ex follows)

ObjectStack versus Stack<String>

```
public class ObjectStack {
  private Object[] elements;
  int size;
  public ObjectStack() {
     elements = new Object[10]; size = 0;}
  public void push(Object item) { elements[size++] = item; }
  public Object peek() { return elements[size-1]; }
  public int size() { return size; }
  public Object pop() { return elements[--size]; }
  public boolean isEmpty() { return (size == 0); }
  public String toString(){
     String s = "Stack: [";
     int i=0;
     for( ; i<size-1; i++){
        s+= elements[i].toString() + "";
     }
     s+= elements[i].toString() + "]";
     return s;}}
```

```
public class TestObjectStack {
   public static void main(String[] args) {
      ObjectStack cityStack = new ObjectStack();
      cityStack.push("New York");
      cityStack.push("London");
      cityStack.push("Paris");
      cityStack.push("Tokyo");
      cityStack.push(22); // ok
      System.out.println("Stack of Cities\n" + cityStack.toString());
      System.out.println("Top element: " + cityStack.peek());
   }
}
```

```
public class TestStack {
   public static void main(String[] args) {

      Stack<String> cityStack = new Stack<>();
      cityStack.push("New York");
      cityStack.push("London");
      cityStack.push("Paris");
      cityStack.push("Tokyo");
      cityStack.push(22);
      System.out.println("Stack of Cities");
      System.out.println(cityStack.toString());
      System.out.println("Top element: " +
            cityStack.peek());
   }
}
```

```
The method push(String) in the type
Stack<String> is not applicable for
the arguments (int)
```

Restrictions on Generics

1. **Cannot create instances using the generic type `<E>`**
   a. The following is incorrect: `E item = new E();`
2. **Cannot create an array of type `E`**
   a. The following is incorrect: `E[] list = new E[20];`
3. **Generic type is not allowed in a static context**
   a. All instances of a generic class share same runtime class
   b. The following are incorrect:

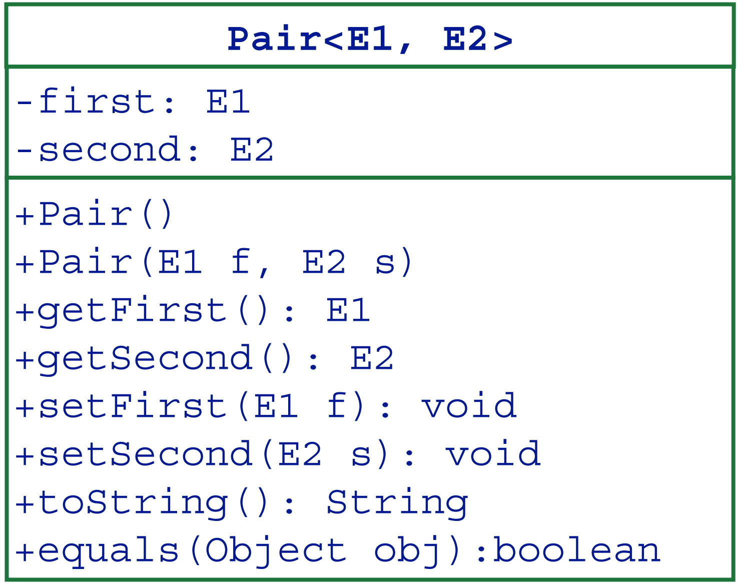
```
public static E item;
public static void m(E object)
```

4. **Exceptions cannot be Generic**
   a. The following are incorrect:

```
public class MyException<T> extends Exception{ }
public static void main(String[] args){
  try{
     Cannot check the thrown exception
  }
  catch(MyException<T> ex){
  }
}
```

Generics: Multiple Types

- **A class may have multiple type parameters (generic types)**
- **Ex:** Class Pair<E1, E2>{}
  - two generic types
  - Pair of string and number (name and id) for example

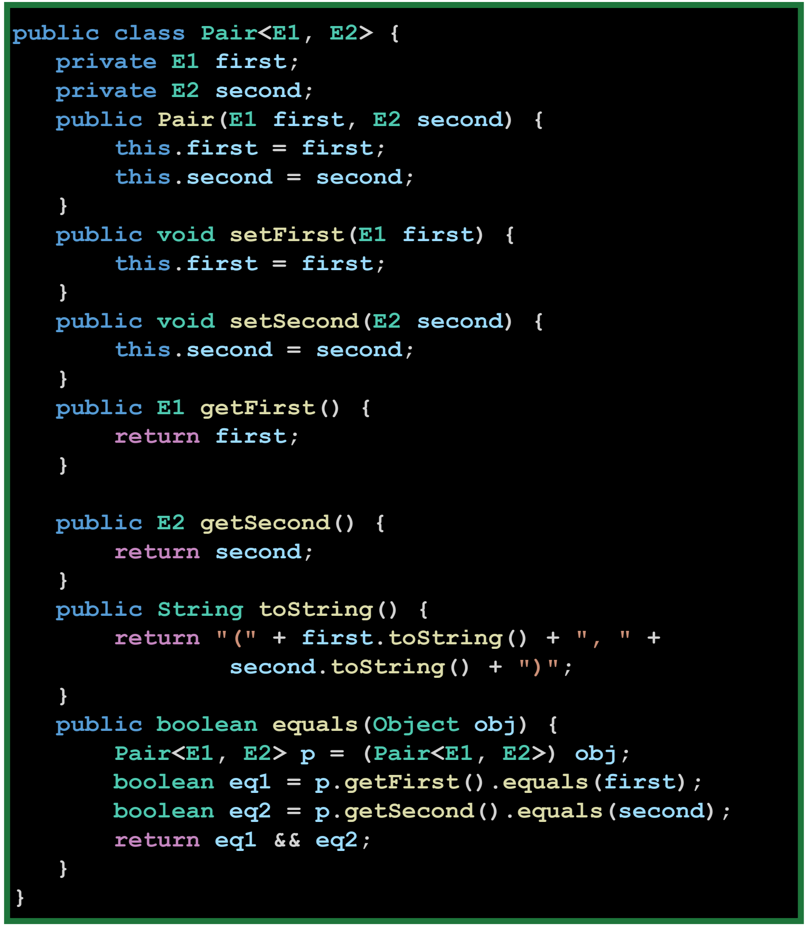


Pair<E1, E2>

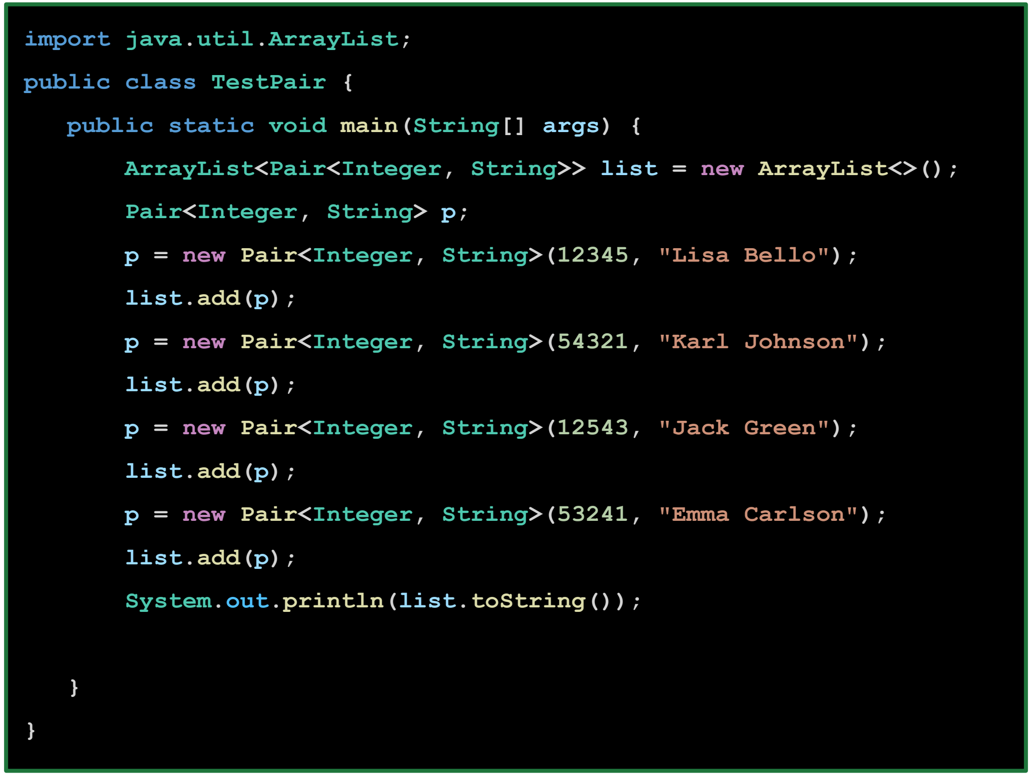
```
-first: E1
-second: E2
```

```
+Pair()
+Pair(E1 f, E2 s)
+getFirst(): E1
+getSecond(): E2
+setFirst(E1 f): void
+setSecond(E2 s): void
+toString(): String
+equals(Object obj):boolean
```

Testing Multiple Generic Types

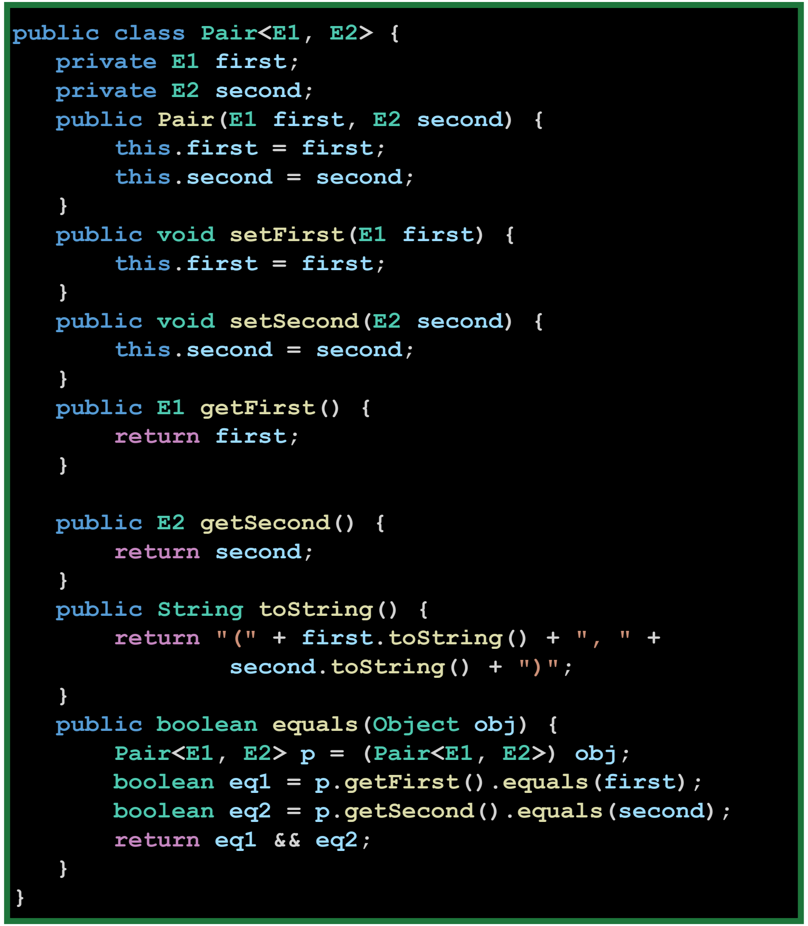


```java
public class Pair<E1, E2> {
    private E1 first;
    private E2 second;
    public Pair(E1 first, E2 second) {
        this.first = first;
        this.second = second;
    }
    public void setFirst(E1 first) {
        this.first = first;
    }
    public void setSecond(E2 second) {
        this.second = second;
    }
    public E1 getFirst() {
        return first;
    }

    public E2 getSecond() {
        return second;
    }
    public String toString() {
        return "(" + first.toString() + ", " +
                second.toString() + ")";
    }
    public boolean equals(Object obj) {
        Pair<E1, E2> p = (Pair<E1, E2>) obj;
        boolean eq1 = p.getFirst().equals(first);
        boolean eq2 = p.getSecond().equals(second);
        return eq1 && eq2;
    }
}
```

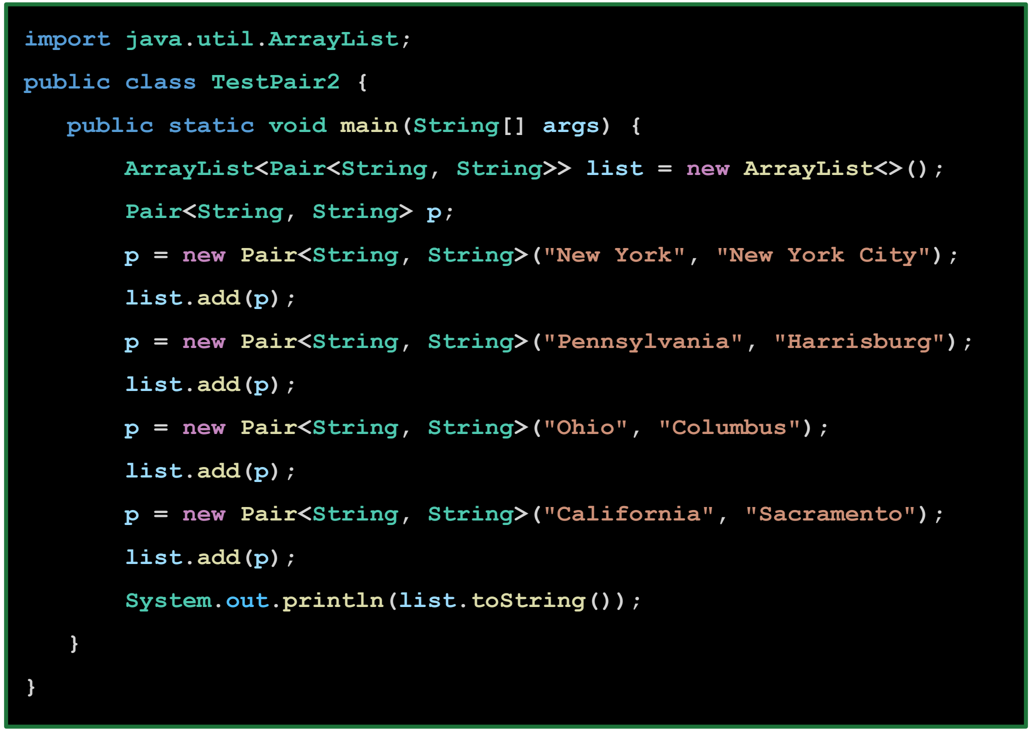


```java
import java.util.ArrayList;

public class TestPair {

    public static void main(String[] args) {

        ArrayList<Pair<Integer, String>> list = new ArrayList<>();

        Pair<Integer, String> p;

        p = new Pair<Integer, String>(12345, "Lisa Bello");

        list.add(p);

        p = new Pair<Integer, String>(54321, "Karl Johnson");

        list.add(p);

        p = new Pair<Integer, String>(12543, "Jack Green");

        list.add(p);

        p = new Pair<Integer, String>(53241, "Emma Carlson");

        list.add(p);

        System.out.println(list.toString());


    }

}
```

Testing Multiple Generic Types



```java
public class Pair<E1, E2> {
   private E1 first;
   private E2 second;
   public Pair(E1 first, E2 second) {
       this.first = first;
       this.second = second;
   }
   public void setFirst(E1 first) {
       this.first = first;
   }
   public void setSecond(E2 second) {
       this.second = second;
   }
   public E1 getFirst() {
       return first;
   }

   public E2 getSecond() {
       return second;
   }
   public String toString() {
       return "(" + first.toString() + ", " +
               second.toString() + ")";
   }
   public boolean equals(Object obj) {
       Pair<E1, E2> p = (Pair<E1, E2>) obj;
       boolean eq1 = p.getFirst().equals(first);
       boolean eq2 = p.getSecond().equals(second);
       return eq1 && eq2;
   }
}
```

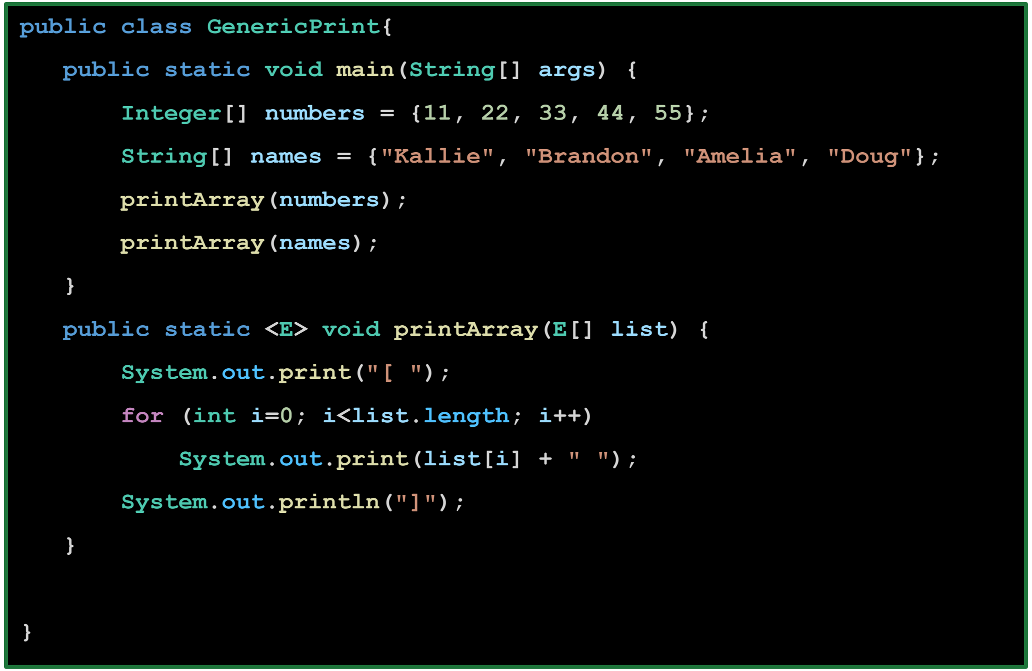


```java
import java.util.ArrayList;
public class TestPair2 {
   public static void main(String[] args) {
       ArrayList<Pair<String, String>> list = new ArrayList<>();
       Pair<String, String> p;
       p = new Pair<String, String>("New York", "New York City");
       list.add(p);
       p = new Pair<String, String>("Pennsylvania", "Harrisburg");
       list.add(p);
       p = new Pair<String, String>("Ohio", "Columbus");
       list.add(p);
       p = new Pair<String, String>("California", "Sacramento");
       list.add(p);
       System.out.println(list.toString());
   }
}
```

Generic Methods

- A method can be generic: parameters or return value are of type generic
  - Does not have to be in a generic class
- Printing arrays of different types `printArray()`
- Searching arrays of different types
- Sorting arrays of different types `java.util.Arrays.sort()`

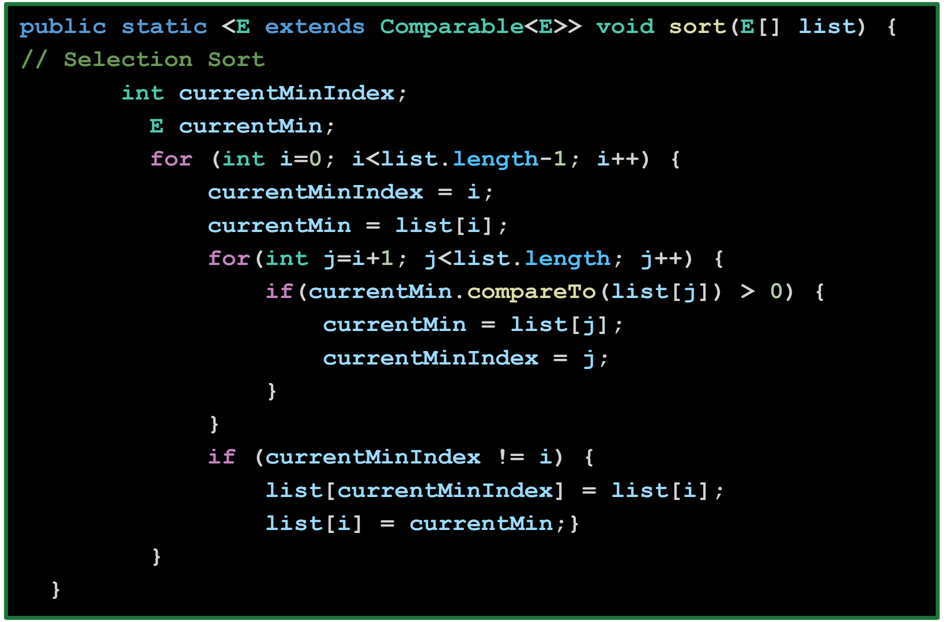
Generic `printArray()`



```
public class GenericPrint{
   public static void main(String[] args) {
       Integer[] numbers = {11, 22, 33, 44, 55};
       String[] names = {"Kallie", "Brandon", "Amelia", "Doug"};
       printArray(numbers);
       printArray(names);
   }
   public static <E> void printArray(E[] list) {
       System.out.print("[ ");
       for (int i=0; i<list.length; i++)
           System.out.print(list[i] + " ");
       System.out.println("]");
   }

}
```

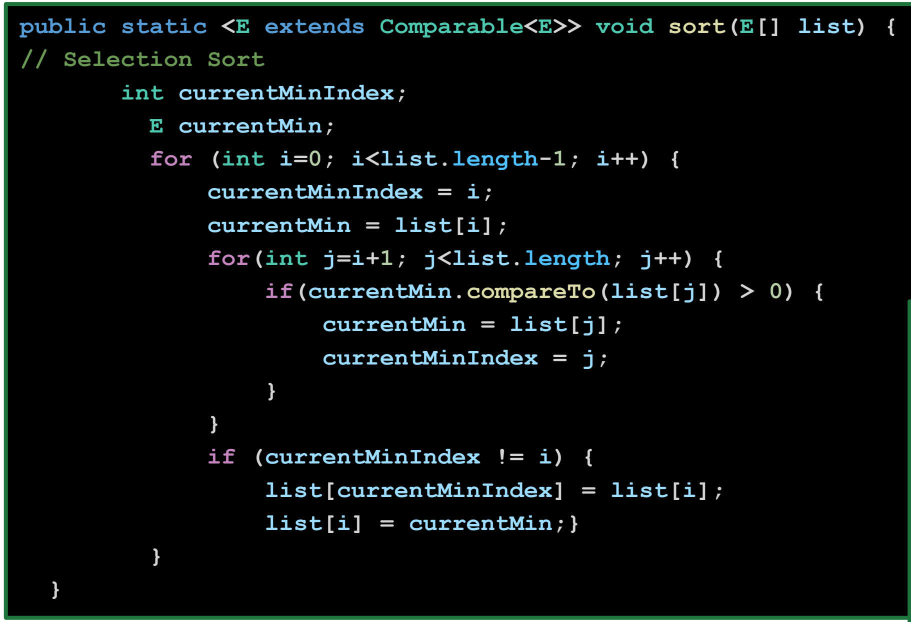
Generic sortArray()

- Sorting arrays of different types `java.util.Arrays.sort()`
- `sort()` needs to compare the elements (order them)
- Elements of the array need to be compared – must be comparable
  - Restrict the generic method to objects that can call compareTo()

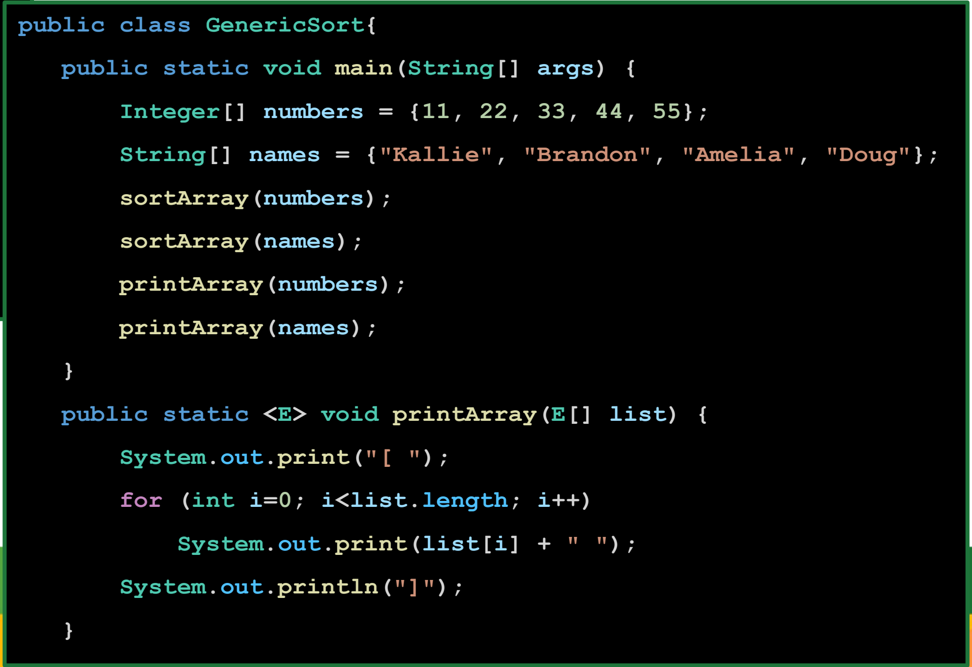


```
public static <E extends Comparable<E>> void sort(E[] list) {
// Selection Sort
       int currentMinIndex;
         E currentMin;
         for (int i=0; i<list.length-1; i++) {
             currentMinIndex = i;
             currentMin = list[i];
             for(int j=i+1; j<list.length; j++) {
                 if(currentMin.compareTo(list[j]) > 0) {
                     currentMin = list[j];
                     currentMinIndex = j;
                 }
             }
             if (currentMinIndex != i) {
                 list[currentMinIndex] = list[i];
                 list[i] = currentMin;}
         }
  }
```

Generic sortArray()



```
public static <E extends Comparable<E>> void sort(E[] list) {
// Selection Sort
       int currentMinIndex;
         E currentMin;
         for (int i=0; i<list.length-1; i++) {
             currentMinIndex = i;
             currentMin = list[i];
             for(int j=i+1; j<list.length; j++) {
                 if(currentMin.compareTo(list[j]) > 0) {
                     currentMin = list[j];
                     currentMinIndex = j;
                 }
             }
             if (currentMinIndex != i) {
                 list[currentMinIndex] = list[i];
                 list[i] = currentMin;}
         }
  }
```



```
public class GenericSort{
   public static void main(String[] args) {
       Integer[] numbers = {11, 22, 33, 44, 55};
       String[] names = {"Kallie", "Brandon", "Amelia", "Doug"};
       sortArray(numbers);
       sortArray(names);
       printArray(numbers);
       printArray(names);
   }
   public static <E> void printArray(E[] list) {
       System.out.print("[ ");
       for (int i=0; i<list.length; i++)
           System.out.print(list[i] + " ");
       System.out.println("]");
   }
```

Using Comparator to sort Shapes

```
<<Interface>>
java.util.Comparator;
```

```
int compare(T obj1, T obj2);
boolean equals(T obj);
```

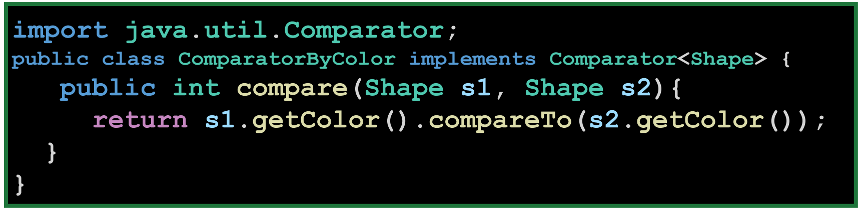
```
java.util.Arrays;
```

```
<E> void sort(E[] list,Comparator<? Super E> c)
```

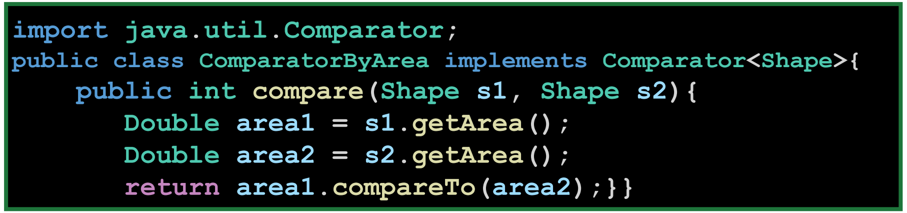
```java
import java.util.Comparator;
public class ComparatorByColor implements Comparator<Shape> {
       public int compare(Shape s1, Shape s2){
      return s1.getColor().compareTo(s2.getColor());
   }
}
```

```java
import java.util.Comparator;
public class ComparatorByArea implements Comparator<Shape>{
  public int compare(Shape s1, Shape s2){
      Double area1 = s1.getArea();
      Double area2 = s2.getArea();
      return area1.compareTo(area2);
    }
}
```

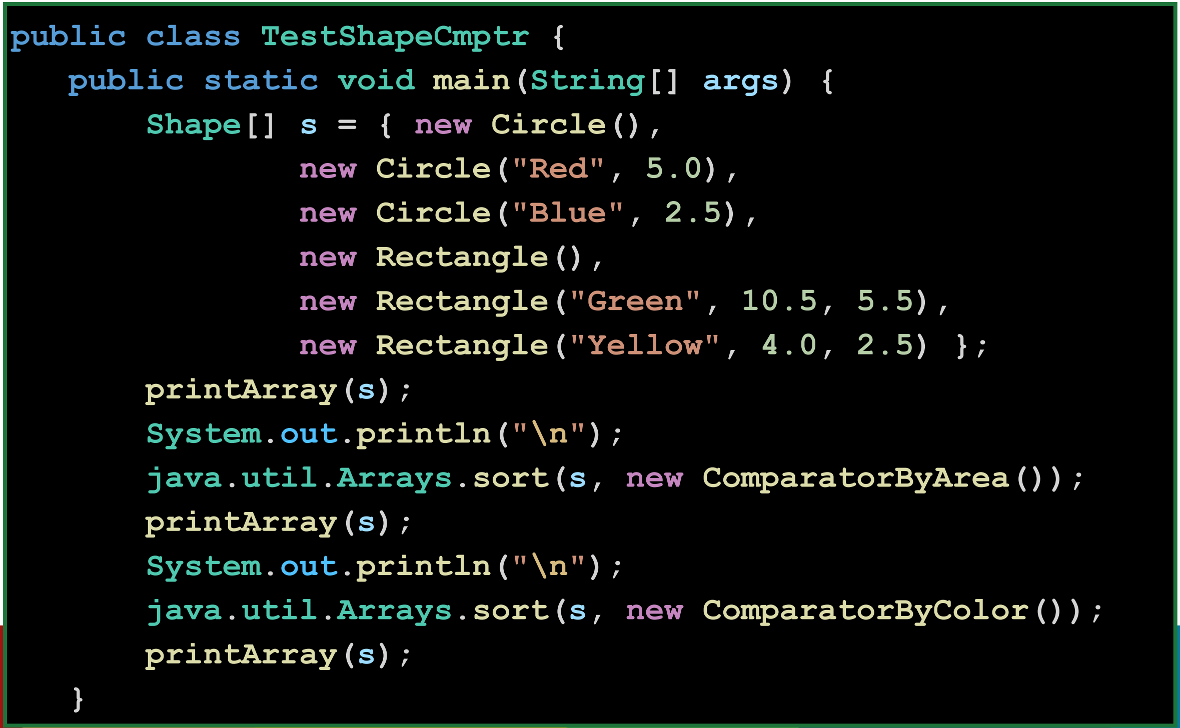
Using Comparator to sort Shapes



```
import java.util.Comparator;
public class ComparatorByColor implements Comparator<Shape> {
   public int compare(Shape s1, Shape s2){
      return s1.getColor().compareTo(s2.getColor());
  }
}
```



```
import java.util.Comparator;
public class ComparatorByArea implements Comparator<Shape>{
    public int compare(Shape s1, Shape s2){
        Double area1 = s1.getArea();
        Double area2 = s2.getArea();
        return area1.compareTo(area2);}}
```



```
public class TestShapeCmptr {
   public static void main(String[] args) {
       Shape[] s = { new Circle(),
               new Circle("Red", 5.0),
               new Circle("Blue", 2.5),
               new Rectangle(),
               new Rectangle("Green", 10.5, 5.5),
               new Rectangle("Yellow", 4.0, 2.5) };
       printArray(s);
       System.out.println("\n");
       java.util.Arrays.sort(s, new ComparatorByArea());
       printArray(s);
       System.out.println("\n");
       java.util.Arrays.sort(s, new ComparatorByColor());
       printArray(s);
   }
```

Shape Comparator Output

```
Type       Color     Dimensions          Area     Perimeter
Circle      Black      1.00              3.14     6.28
Circle      Red        5.00              78.54    31.42
Circle      Blue       2.50              19.63    15.71
Rectangle   Black      1.00      1.00    1.00     4.00
Rectangle   Green      10.00     5.50    55.00    31.00
Rectangle   Yellow     4.00      2.50    10.00    13.00
List of shapes sorted by area:
Rectangle   Black      1.00      1.00    1.00     4.00
Circle      Black      1.00               3.14    6.28
Rectangle   Yellow     4.00      2.50    10.00    13.00
Circle      Blue       2.50              19.63    15.71
Rectangle   Green      10.00     5.50    55.00    31.00
Circle      Red        5.00              78.54    31.42
List of shapes sorted by color:
Rectangle   Black      1.00      1.00    1.00     4.00
Circle      Black      1.00              3.14     6.28
Circle      Blue       2.50              19.63    15.71
Rectangle   Green      10.00     5.50    55.00    31.00
Circle      Red        5.00              78.54    31.42
Rectangle   Yellow     4.00      2.50    10.00    13.00
```

Raw Type Generics

- A generic class or interface used **without specifying a concrete type** is raw type and will be replaced with `Object` at compile time
  - `Stack stack = new Stack();`

    Is equivalent to:
  - `Stack<Object> = new Stack<>();`
- **Raw types are used for backward compatibility only**
  - Old Java version of the interface Comparable is not generic
    - `int compareTo(Object obj)`
  - Don't use unless backwards compatibility is required
- **Raw types are unsafe – may generate runtime errors**

Wildcard Generic Types

- **Generic types replaces with object types at compile time**
  - If bounded (see below), replace with bounded type
- **Generic type can be restricted to specific types or groups of types**
  - `<E extends Comparable<E>>` restricts the type `E` to be a `subtype of Comparable`
- **Types of wildcards:**
  - **Unbounded** `(?)`: no restrictions
    - Equivalent to `? extends Object`
  - **Bounded** `(? extends T)`: Generic Type must be `T` or a subtype of `T`
  - **Lower-bound** `(? Super T)`: Generic type must be `T` or super type of `T`

Examples of Wildcard Generic Types

Unbounded: Parameter is a Stack with any type that extends **`Object`**

```
public static void print(Stack<?> stack) {
       System.out.print("From top: [");
       while(!stack.isEmpty()) {
             System.out.print(stack.peek() + ", ");
          stack.pop();
       }
       System.out.println("]");    }
```

Bounded: Parameter `stack2` must be of type `T` or a `super type of T`

```
public static <T> void add(Stack<T> stack1, Stack<? super T> stack2) {
       while (!stack1.isEmpty()) {
           stack2.push(stack1.pop());
       }
   }
```

Examples of Wildcard Generic Types

```java
public static void main(String[] args) {
    Stack<String> cities = new Stack<>();
    cities.push("New York");
    cities.push("London");
    cities.push("Paris");
    cities.push("Tokyo");

    Stack<Object> mix = new Stack<>();
    mix.push("Bangkok");
    mix.push(333);
    mix.push(75.25);

    add(cities, mix); // OK
    print(mix);
  }
```

```java
public static void main(String[] args) {
    Stack<String> cities = new Stack<>();
    cities.push("New York");
    cities.push("London");
    cities.push("Paris");
    cities.push("Tokyo");
    Stack<Integer> mix = new Stack<>();
    mix.push(1267);
    mix.push(333);
    mix.push(755);
    add(cities, mix); // Error
    print(mix);
}
```

```
The method add(Stack<T>, Stack<? super T>) in
the type TestStack is not applicable for the
arguments (Stack<String>, Stack<Integer>)
```

Class Summary: Generics

- Generic classes and interfaces
- Generic methods
- Raw types (unsafe)
- Restrictions on generic types
- Wildcard generic types