301AA - Advanced Programming

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***AP-20**: Lambdas and Streams in Java 8*

Java 8: language extensions

Java 8 is the biggest change to Java since the inception of the language. Main new features:

- Lambda expressions
  - Improved type inference
  - Anonymous functions
  - Method references
  - Default methods in interfaces
- Stream API

A big challenge was to introduce lambdas without requiring recompilation of existing binaries

Benefits of Lambdas in Java 8

- Enabling functional programming
  - Being able to pass behaviors as well as data to functions
  - Introduction of lazy evaluation with stream processing
- Writing cleaner and more compact code
- Facilitating parallel programming
- Developing more generic, flexible and reusable APIs

Lambda expression syntax: Print a list of integers with a lambda

```
List<Integer> intSeq = Arrays.asList(1,2,3);

intSeq.forEach(x -> System.out.println(x));
```

`x -> System.out.println(x)`

is a **lambda expression** that defines an **anonymous function (method)** with one parameter named **`x`** of type Integer

```
// equivalent syntax
intSeq.forEach((Integer x) -> System.out.println(x));

intSeq.forEach(x -> {System.out.println(x);});

intSeq.forEach(System.out::println); //method reference
```

- Type of parameter inferred by the compiler if missing

Multiline lambda, local variables, no new scope

```
List<Integer> intSeq = Arrays.asList(1,2,3);
// multiline: curly brackets necessary
// local variable declaration
intSeq.forEach(x -> {
   int y = x + 2;
   System.out.println(y);
});


// no new scope!!!
int x = 0, y = 0;
intSeq.forEach(x -> {       //error: x already defined
    double y = 2.0;         //error: y already defined
    System.out.println(x + y);
});
```

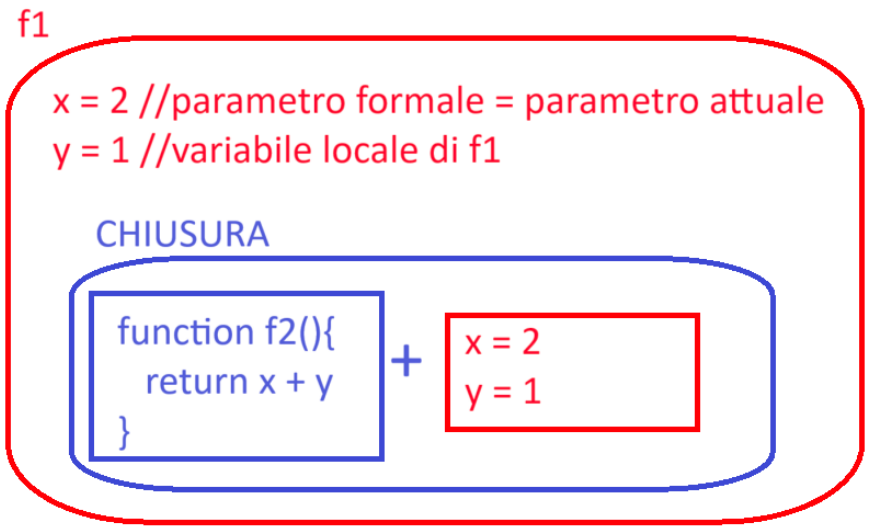
Assigning, passing as argument and returning lambdas

```
// lambda expressions can be assigned and returned
import java.util.*;
import java.util.function.*;
class Lambdas {
    public static void main(String... args){
        Arrays.asList(args).forEach(print());
    }

    public static Consumer<String> print(){
        Consumer<String> cons = (y -> System.out.println(y));
        return cons;
    }
}
```

Closures

- Closures needed in general when functions can be passed to or returned by functions
- Example in pseudocode (not Java!)

```
function f1(x: Int) -> (Void -> Int) {
  var y: Int = 1
  function f2() -> Int {
    return x + y
  }
  return f2
}

var esempio: (Void -> Int) = f1(2)
print(esempio()) //Output: 3
```



Local and Static Variable Capture

- **Local variables** used inside the body of a lambda must be **final** or **effectively final**

```
public class LVCExample {      // local variable capture
  public static void main(String[] args) {
    List<Integer> intSeq = Arrays.asList(1,2,3);

    int var = 10;              // must be [effectively] final
    intSeq.forEach(x -> System.out.println(x + var));
    // var = 3; // uncommenting this line it does not compile
  }
}
```

This is a fundamental design choice, as it makes closures not necessary

```
public class SVCExample {      // static variable capture
  private static int var = 10;
  public static void main(String[] args) {
    List<Integer> intSeq = Arrays.asList(1,2,3);

    intSeq.forEach(x -> System.out.println(x + var));
    var = 3;          // it compiles
  }
}
```

Implementation of Java 8 Lambdas

- The Java 8 compiler conceptually first converts a lambda expression into a function, compiling its code
- Then it generates code to call the compiled function where needed
- For example, `x -> System.out.println(x)` could be converted into a generated static function

```
public static void genName(Integer x) {
    System.out.println(x);
}
```

- But what type should be generated for this function? How should it be called? What class should it go in?

Functional Interfaces

- Design decision: Java 8 lambdas are instances of *functional interfaces*.
- A **functional interface** is a Java interface with **exactly one abstract method**. E.g.,

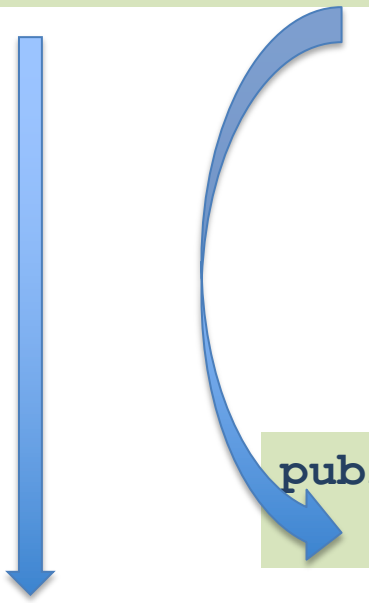
```
public interface Comparator<T> { //java.util
   int compare(T o1, T o2);
}

public interface Runnable {   //java.lang
   void run();
}

public interface Consumer<T>{   //java.util.function
    void accept(T t)
}

public interface Callable<V> {//java.util.concurrent
   V call() throws Exception;
}
```

Functional interfaces and lambdas

- Functional Interfaces can be used as *target type* of lambda expressions, i.e.
  - As type of variable to which the lambda is assigned
  - As type of formal parameter to which the lambda is passed
- The compiler uses type inference **based on target type**
- Arguments and result types of the lambda must match those of the unique abstract method of the functional interface
- The lambda is invoked by calling the only abstract method of the functional interface
- Lambdas can be interpreted as **instances** of **anonymous inner classes** implementing the functional interface

Expanding a lambda

```
List<Integer> intSeq = Arrays.asList(1,2,3);
intSeq.forEach(x -> System.out.println(x));
```



```
        // List<T> extends Iterable<T>
interface Iterable<T>{      //java.lang
default void forEach(Consumer<? super T> action)
    for (T t : this)
        action.accept(t);
```

```
public interface Consumer<T>{ //java.util.function
  void accept(T t);  }    //functional interface
```

```
List<Integer> intSeq = Arrays.asList(1,2,3);
for (Integer t:intSeq)
    System.out.println(t);
```

An example: From inner classes pre Java 8...

```
public class Calculator1 {  // Pre Java 8
    interface IntegerMath { // (inner) functional interface
        int operation(int a, int b);
    }
    public int operateBinary(int a, int b, IntegerMath op) {
        return op.operation(a, b);
    } // parameter type is functional interface
```

```
    // inner class implementing the interface
    static class IntMath$Add implements IntegerMath{
        public int operation(int a, int b){
            return a + b;
        }}
    public static void main(String... args) {
        Calculator1 myApp = new Calculator1();
        System.out.println("40 + 2 = " +
                myApp.operateBinary(40, 2, new IntMath$Add()));
    // anonymous inner class implementing the interface
        IntegerMath subtraction = new IntegerMath(){
                public int operation(int a, int b){
                    return a - b;
                };
        };
        System.out.println("20 - 10 = " +
                myApp.operateBinary(20, 10, subtraction));  }}
```

… to lambda expressions

```
public class Calculator {

    interface IntegerMath { // (inner) functional interface
        int operation(int a, int b);
    }

    public int operateBinary(int a, int b, IntegerMath op) {
        return op.operation(a, b);
    }     // parameter type is functional interface

    public static void main(String... args) {
        Calculator myApp = new Calculator();
            // lambda assigned to functional interface variables
        IntegerMath addition = (a, b) -> a + b;
        System.out.println("40 + 2 = " +
            myApp.operateBinary(40, 2, addition));
            // lambda passed to functional interface formal parameter
        System.out.println("20 - 10 = " +
            myApp.operateBinary(20, 10, (a, b) -> a - b));
    }
}
```

From Lambdas to Bytecode

- Lambdas can, in principle, be compiled as instances of anonymous inner classes
- Neither JLS 8 nor JVMS 8 prescribe a specific compilation strategy for lambdas
- The strategy is left to the designer of the compiler, which can exploit this freedom on behalf of efficiency
- Current compilers use the **invokedynamic** instruction of the JVM. It allows to defer to runtime the computation of a call-site.
- Let's explore with godbolt.org

Other examples of lambdas: Runnable

```
public class ThreadTest {// using functional interface Runnable
  public static void main(String[] args) {
    Runnable r1 = new Runnable() { // anonymous inner class
      @Override
      public void run() {
        System.out.println("Old Java Way");
      }
    };

    new Thread(r1).start();
    // using lambda expression
    Runnable r2 = () -> { System.out.println("New Java Way"); };

    new Thread(r2).start();
  }
}
```

```
// constructor of class Thread

public Thread(Runnable target)
```

Other examples of lambdas: Listener

```
JButton button = new JButton("Click Me!");

// pre Java 8
button.addActionListener(new ActionListener() {
    public void actionPerformed(ActionEvent evt) {
        System.out.println("Handled by anonymous class listener");
    }
});


// Java 8
button.addActionListener(
    e -> System.out.println("Handled by Lambda listener"));
```

New Functional Interfaces in package java.util.function

```
public interface Consumer<T> {          //java.util.function
   void accept(T t);
}
public interface Supplier<T> {          //java.util.function
   T get();
}
public interface Predicate<T> {         //java.util.function
   boolean test(T t);
}
public interface Function <T,R> {       //java.util.function
   R apply(T t);
}
```

Other examples of lambdas

```
List<Integer> intSeq =  new ArrayList<>(Arrays.asList(1,2,3));

// sort list in descending order using Comparator<Integer>
intSeq.sort((x,z) -> z - x);  // lambda with two arguments
intSeq.forEach(System.out::println);


// remove odd numbers using a  Predicate<Integer>
intSeq.removeIf(x -> x%2 == 1);
intSeq.forEach(System.out::println); // prints only '2'
```

But, where do the **sort**, **removeIf** and **forEach** methods come from?

```
// default method of Interface List<E>
default void sort(Comparator<? super E> c)
// default method of Interface Collection<E>
default boolean removeIf(Predicate<? super E> filter)
// default method of Interface Iterable<T>
default void forEach(Consumer<? super T> action)
```

Default Methods

Problem: Adding new abstract methods to an interface breaks existing implementations of the interface

Java 8 allows interface to include

- Abstract (instance) methods, as usual
- **Static methods**
- **Default methods**, defined in terms of other possibly abstract methods

Java 8 uses lambda expressions and default methods in conjunction with the Java collections framework to achieve *backward compatibility* with existing published interfaces

Method References

- Method references can be used to pass an existing function in places where a lambda is expected
- The signature of the referenced method needs to match the signature of the functional interface method

Method Reference Type	Syntax	Example
static	ClassName::StaticMethodName	String::valueOf
constructor	ClassName::new	ArrayList::new
specific object instance	objectReference::MethodName	x::toString
arbitrary object of a given type	ClassName::InstanceMethodName	Object::toString

Summary

- Lambda expressions allow to define anonymous methods and to handle them as first-class objects
- Their types are functional interfaces, using type inference
- Certain typical coding patterns can be greatly simplified
- They are widely used in the Stream API
- Neither JLS 8 nor JVMS 8 prescribe a specific compilation strategy for lambdas
- For a discussion about the possible compilation strategies and the choice of using **invokedynamic** to defer the choice to runtime, see
  From Lambdas to Bytecode by Brian Goetz