(6) Java Abstractions: Interfaces – Part 2

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TOC

- Cited Literature:
  - Just Java, Peter van der Linden
  - Thinking in Java, Bruce Eckel

Initial Words

Yes, my slides are heavy.

I do so, because I want people to go through the slides at their own pace w/o having to watch an accompanying video.

On each slide you'll find the crucial information. In the notes to each slide you'll find more details and related information, which would be part of the talk I gave.

Have fun!

Local Classes

- In another lecture, we have already discussed nested UDTs. Those are UDTs, which are defined within another UDT.

- Additionally, Java allows the definition of local classes. Those are classes, which are defined within the code of a method.
  - The class within the method is called local class.
  - The method, in which the local class is defined, is called enclosing method.
    - The enclosing method can access the local classes private members.
  - The type of the class, in which the local class is defined, is called outer class/type.

local class

enclosing method

outer type/class

```java
// <Program.java>
public class Program {
    public static void main(String[] args) {
        class LocalClass {
            public void testMethod() {
                System.out.println("in LocalClass.testMethod()");
            }
        }

        LocalClass localClassInstance = new LocalClass();
        localClassInstance.testMethod();
        // >in LocalClass.testMethod()
    }
}
```

- Limitations of local classes:
  - We cannot have static members in local classes.
  - We cannot have local interfaces or enums.

Local Classes as Sub Classes

- A crucial point about local classes: they can inherit from other classes and implement interfaces like non-local classes:

```
// <Program.java>
public class Program {
        public static void main(String[] args) {
            class LocalCar extends Car implements GasAcceptor {
                private double liters;
                public void testMethod(double liters) {
                    System.out.println("in LocalClass.testMethod()");
                }
                @Override
                public void fillGas(double liters) {
                    this.liters = liters;
                    System.out.printf("Refueled with %.2f liters%n.", liters);
                }
            }

            LocalCar localClassInstance = new LocalCar();
            localClassInstance.testMethod();
            // >in LocalClass.testMethod()
            joesStation.refuel(localClassInstance, 20.4);
            // >Refueled with 20.40 liters.
        }
}
```

  - Now, *LocalClass* extends *Car*, implements *GasAcceptor* and *@Override*s the method *GasAcceptor.fillGas()*!

- We can also define abstract or final local classes.

The Code of Local Classes

- The code of local classes:
  - (1) is allowed to read local variables of the enclosing method's local scope and fields, also non-public ones, of the outer class.
    - If a variable of the enclosing method's local scope is used in a local class, it is said to be a captured variable.
  - (2) is allowed to call methods, also non-public ones, of the outer UDT.
  - (3) is allowed to write fields of the outer UDT.

```
// <Program.java>
public class Program {
	public static void main(String[] args) {
		String message = "LocalCar";
		class LocalCar extends Car implements GasAcceptor {
			private double liters;
			@Override
			public void fillGas(double liters) {
				this.liters = liters;
				System.out.printf("Refueled %s with %.2f liters%n.", message, liters);
			}
		}

		joesStation.refuel(new LocalCar(), 20.4);
		// >Refueled LocalCar with 20.40 liters.
	}
}
```

message as captured variable

- Local classes are not allowed to write captured variables. Captured variables are effectively final.
  - Effectively final means, that they need not to be declared final, but as a matter of fact they are final as soon as they are captured.
  - Effectively finals are also final outside of the local class in the enclosing methods.

```
// <Program.java>
public class Program {
	public static void main(String[] args) {
		String message = "LocalCar";
		class LocalCar extends Car implements GasAcceptor {
			private double liters;
			@Override
			public void fillGas(double liters) {
				message = "other text";
			}
		}
	}
}
```


- Before Java 8 it was required to define captured variables of the enclosing method's local scope as final explicitly. Since Java 8, local variables, which are only read after initialization are implicitly final, i.e. eventually final.

Introducing anonymous Classes

- This is a very important topic in Java! Esp. to create so called event handlers.
- Java even allows to create local anonymous classes and immediate instances thereof:

```
// <Program.java>
public class Program {
    public static void main(String[] args) {
        Car localCarInstance = new Car() {
            @Override
            public void startEngine() {
                System.out.println("start a local Car");
            }
        };

        localCarInstance.startEngine();
        // >start a local Car
    }
}
```

anonymous class

Notice
Different from the definition of a local class, the definition of an anonymous class is a statement, which must be terminated with a semicolon!

- Several things are happening in this compact code.
  - (1) On the right side of the assignment
    - (a) a new anonymous class is created, which inherits from *Car*
    - (b) an instance of that anonymous class is created.
  - => An anonymous class is a sub class UDT without a name.
  - (2) On the left side of the assignment
    - a reference of type *Car* holds the new instance.

```
// (1) … gets assigned an instance of an anonymous class, which inherits Car:
… new Car() {
    @Override
    public void startEngine() {
        System.out.println("start a local Car");
    }
};
```

```
// (2) An instance of type Car ...:
Car localCarInstance = …
```

Calling super Ctors of anonymous Classes

- It is syntactically not directly obvious, but calling super ctors along with creating anonymous classes is possible.
  - Assume *Car* with a ctor accepting a car's vehicle id:

```
public class Car { // (other members omitted)
	private final String vehicleID;

	public Car(String vehicleID) {
		this.vehicleID = vehicleID;
	}
	public String getVehicleID() {
		return this.vehicleID;
	}
	public void startEngine() {
	}
}
```

- Principally, the super classes ctor is just called during the initialization of the anonymous classes instance.

```
// <Program.java>
public class Program {
	public static void main(String[] args) {
		Car localCarInstance = new Car("W0L000051T2123456") {
			@Override
			public void startEngine() {
				System.out.printf("starting '%s'%n", getVehicleID());
			}
		};

		localCarInstance.startEngine();
		// >starting 'W0L000051T2123456'
	}
}
```

calls the ctor of the anonymous classes super class (*Car* in this case)

Local (incl. anonymous) Classes and the Scope of this and super

- The this reference of a local class refers to its current instance, e.g. we can call a private method on this:

```
public static void main(String[] args) {
        class LocalClass {
                private void anotherTestMethod() { System.out.println("in LocalClass.anotherTestMethod()"); }
                public void testMethod() {
                        this.anotherTestMethod();
                }
        }

        LocalClass localClassInstance = new LocalClass();
        localClassInstance.testMethod();
        // >in LocalClass.anotherTestMethod()
}
```

- The super reference of a local class refers to the super classes part of the current instance:

```
public class Car { // (other members omitted)
        private String vehicleID;

        public Car(String vehicleID) {
                this.vehicleID = vehicleID;
        }

        public String getVehicleID() {
                return this.vehicleID;
        }

        public void startEngine() {
                System.out.println("in Car.startEngine()");
        }
}
```

```
public static void main(String[] args) {
        class LocalCar extends Car {
                @Override
                public void startEngine() {
                        super.startEngine();
                }
        }

        LocalCar localCarInstance = new LocalCar();
        localCarInstance.startEngine();
        // >in Car.startEngine()
}
```

Anonymous Classes from Interfaces

- In Java we can go yet another step: We can create an anonymous class instantiated from an interface!

```java
// <Program.java>
public class Program {
        public static void main(String[] args) {
                GasAcceptor aGasAcceptor = new GasAcceptor() {
                        @Override
                        public void fillGas(double liters) {
                                System.out.printf("filling %.2fl of gas%n", liters);
                        }
                };

                joesStation.refuel(aGasAcceptor, 34.8);
                // >filling 34.80l of gas
        }
}
```

«interface»
GasAcceptor
+ fillGas(liters : double)

Good to know
An anonymous class instantiated from an interface implicitly extends *Object*. Of course it does, because all UDTs extend *Object* as ultimate super class. It means, we could also *@Override* any method derived from *Object* (e.g. *Object.toString()*) in an anonymous class instantiated from an interface!

- This code is similar to the creation of an anonymous class on the last slide, but this time we implement an interface.
  - On the right side of the assignment
    - (a) a new anon. class is created, which implements *GasAcceptor*
    - (b) an instance of that anonymous class is created.

```java
// (1) … gets assigned an instance of a new UDT, which implements GasAcceptor:
… new GasAcceptor() {
        @Override
        public void fillGas(double liters) {
                System.out.printf("filling %.2fl of gas%n", liters);
        }
};
```

  - On the left side of the assignment
    - a reference of type *GasAcceptor* holds the new instance.

```java
// (2) An instance of type GasAcceptor ...:
GasAcceptor aGasAcceptor = …
```

Using anonymous Classes in Fields

- Up to now we've seen local anonymous classes, but anonymous classes can also be nested!
  - I.e. anonymous classes can also be created and used as types of fields of outer types!

```java
// <Program.java>
public class Program {
	public static void main(String[] args) {
		GasAcceptor aGasAcceptor = new GasAcceptor() {
			@Override
			public void fillGas(double liters) {
				System.out.printf("filling %.2fl of gas%n", liters);
			}
		};
		Car aCarInstance = new Car() {
			@Override
			public void startEngine() {
				System.out.println("start a local Car");
			}
		};
	}
}
```

from local to nested anonymous classes

```java
// <OuterClass.java>
public class OuterClass {
	private GasAcceptor aGasAcceptor = new GasAcceptor() {
		@Override
		public void fillGas(double liters) {
			System.out.printf("filling %.2fl of gas%n", liters);
		}
	};
	private Car aCarInstance = new Car() {
		@Override
		public void startEngine() {
			System.out.println("start a nested Car");
		}
	};
}
```

- The code of nested anonymous classes:
  - (1) is allowed to read and write and capture fields of the outer class (*OuterClass* in this case), also private ones
  - (2) is allowed to call methods of the outer class (*OuterClass* in this case), also private ones.

Using anonymous Classes – Limitations

- Anonymous classes must either implement an interface or extend a class during creation.
  - It can only directly implement one interface at creation time. Then it implicitly extends the class *Object*!
  - It cannot implement an interface and additionally extend a class at creation time.
- Instead we can, e.g., create local classes to build "mini-hierarchies" to come over such limitations:

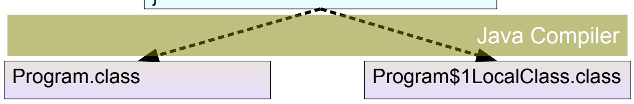
```
public void method() {
	class LocalCarImpl extends Car implements GasAcceptor {
		public LocalCarImpl(String vehicleID) {
			super(vehicleID);
		}
		@Override
		public void fillGas(double liters) {
			System.out.printf("filling %.2fl of gas%n", liters);
		}
	}
	Car localCarInstance = new LocalCarImpl("W0L000051T2123456") {
		@Override
		public void startEngine() {
			System.out.printf("starting '%s'%n", getVehicleID());
		}
	};

	localCarInstance.startEngine();
	// >starting 'W0L000051T2123456'
}
```

  - *LocalCarImpl* was just added as "relay" class to get a class extending *Car* and implementing *GasAcceptor*.
  - … then the following code can extend *LocalCarImpl* and *@Override* inherited methods.

Local and anonymous Classes and the Java Compiler

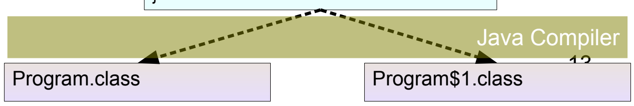
- Like with static nested classes, the compiler creates class-files for local and anonymous classes with structured names.
  - Per **local (named) class**, we get a class-file with the outer class name and after the '$' a uniquely numbered local class name:
    - The unique number is needed, because we could have local classes with the same name in different methods of the same outer class.

```
// <Program.java>
public class Program {
        public static void main(String[] args) {
                class LocalClass {
                }
        }
}
```



  - Per **anonymous class**, we get a class-file with the outer class name and after the '$' a unique number as class name:
    - This is also true for non-local anonymous classes (e.g. in field definitions), all anonymous classes of an outer class are just consecutively numbered.

```
// <Program.java>
public class Program {
        public static void main(String[] args) {
                Car localCarInstance = new Car() {
                        // An anonymous class
                };
        }
}
```



Initializer Blocks

- Sometimes it is required to do initialization of an anonymous class, e.g. to initialize fields.
  - But how can fields be initialized, when fields are usually private? – Sure, with ctors! But there is a problem...
- Because an anonymous class has no name, we cannot define a ctor!
  - Therefor Java allows to write so called initializer blocks. They allow to create a dctor in an anonymous class!
  - Initializer blocks are sometimes called instance initializer blocks.

```
// <Program.java>
public class Program {
	public static void main(String[] args) {
		Car localCarInstance = new Car() {
			{
				System.out.println("in initializer block");
			}
		};
		// >in initializer block
	}
}
```

- Initializer blocks represent code, which is written in curly braces on an (anonymous) classes member level.
  - Initializer blocks can access members and read/write fields of (anonymous) classes.
    - Yes, we can also define initializer blocks in named (i.e. "non-anonymous"/"normal") classes!
  - Like ctors, initializer blocks are executed, when an instance of the class is created.
  - Internally, initializer blocks are executed, after the super classes ctor returns.
  - We can have several initializer blocks in a class, which are executed in the order they are written. -> This is very error prone!

Excursus: Static Initializer Blocks

- After we have introduced initializer blocks, we'll also introduce static initializer blocks.
  - If, for whatever reason, a static field cannot be assigned "inline", it can be done in a static initializer block:

```java
public class Date { // (members hidden)
        public static final double S_PER_GREGORIAN_YEAR;

        static {
            SECONDS_PER_GREGORIAN_YEAR = 31556952.2;
        }
}
```

- Typically, the code in the static block will be executed exactly once, when a program using *Date* is started.
  - Warning: The code in static initializer blocks is executed, when a class is initialized, i.e. there is no *main()*-method required!
  - Harmless-looking code put into a static initializer block can cover difficult to explain effects or bugs:

```java
public class Date { // (members hidden)
        static { // Will always be executed, when the class Date is initialized.
            System.out.println("Hello World!!!");
        }
        // >Hello World!!!
}
```

- static initializer blocks are used rarely.
  - We can have several of those blocks in a class, which are executed in the order they are written. -> This is very error prone!

- Questions about when a static block is executed are difficult to answer. Most sources tell, that this happens, when a class is initialized. Sometimes it is said, that it is executed, when a class is loaded by the VM (btw., this seems to be wrong).
- Like with non-static initializer blocks, we can have several static initializer blocks in a class, which are executed in the order they are written. This is also very error prone, because it is tempting to rely on any orders of execution!

Anonymous Classes from Interfaces – Method References

- As alternative to anonymous classes, we can use method references to implement single-method-interfaces.
  - The target types of method references must be interfaces with one method. – We call those interfaces functional interface types.

```
// <Program.java>
public class Program {
	public static void main(String[] args) {
		GasAcceptor aGasAcceptor = new GasAcceptor() {
			@Override
			public void fillGas(double liters) {
				System.out.printf("filling %.2fl of gas%n", liters);
			}
		};

		joesStation.refuel(aGasAcceptor, 34.8);
		// >filling 34.80l of gas
	}
}
```

from anonymous class to method

```
// <Program.java>
public class Program {
	public static void accept(double liters) {
		System.out.printf("filling %.2fl of gas%n", liters);
	}

	public static void main(String[] args) {
		// This method reference overrides GasAcceptor.fillGas():
		GasAcceptor aGasAcceptor = Program::accept;

		joesStation.refuel(aGasAcceptor, 34.8);
		// >filling 34.80l of gas
	}
}
```

reference the method to implement the interface

«interface»
GasAcceptor
+ fillGas(liters : double)

- If we have a method, which matches the signature of a functional interface, we can use a reference to this method as valid implementation of that interface w/o creation of an anonymous class!
- Attention! Underneath method references don't create anonymous classes! Instead Java's inkovedynamic is used.
- But Java provides yet another shortcut to implement functional interfaces with so called lambda expressions...

- To be a functional interface, an interface is only allowed to have exactly one abstract method! – It means, that other methods must be default methods (or static methods, but they don't contribute to the "contract-nature" of an interface).
- Functional interface types are sometimes also called Single Abstract Method (SAM) types.
- No anonymous class is generated for method references, notice that no class-file like one for an inner class is created.

Anonymous Classes from Interfaces – Lambda Expressions

- As alternative to anonymous classes, we can use lambda expressions to implement functional interfaces.
  - Read: The target type of lambda expressions must also be a functional interface.

```
// <Program.java>
public class Program {
	public static void main(String[] args) {
		GasAcceptor aGasAcceptor = new GasAcceptor() {
			@Override
			public void fillGas(double liters) {
				System.out.printf("filling %.2fl of gas%n", liters);
			}
		};

		joesStation.refuel(aGasAcceptor, 34.8);
		// >filling 34.80l of gas
	}
}
```

from local class to lambda expression

«interface» **GasAcceptor**
+ fillGas(liters : double)

```
// <Program.java>
public class Program {
	public static void main(String[] args) {
		GasAcceptor aGasAcceptor
			// This lambda expression overridesGasAcceptor.fillGas():
			= (double liters) -> { System.out.printf("filling %.2fl of gas%n", liters); };

		joesStation.refuel(aGasAcceptor, 34.8);
		// >filling 34.80l of gas
	}
}
```

- A lambda expression, aka "lambda", is a compact way to create an ad hoc implementation of a functional interface.
  - Lambdas are very powerful, because they allow writing powerful, yet compact code.
    - As a matter of fact, the presented definition of the lambda expression can be written even more compact!
  - Since its introduction with Java 8, the lambda-idiom changed programming in Java profoundly.
  - We'll discuss lambdas in depth and in a future lecture. Then we'll understand, that lambdas are a game-changer in Java.
  - => Lambdas are a deep key enabler for Java's *Streams*.

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- Attention! Underneath lambdas don't create anonymous classes! Instead Java's inkovedynamic is used.

- Captured symbols must also be effectively final in lambdas.
- No anonymous class is generated for lambdas: notice that no class-file like one for an inner class is created.

Anonymous Classes – Summary

- The definition of anonymous classes is tied to present UDTs.
  - Anonymous classes must extend an existing class or implement an existing interface!
- Implementation side of anonymous classes:
  - Anonymous classes cannot be abstract (can't define abstract methods), indeed, they are implicitly final.
  - Therefor, anonymous classes have to @*Override* or implement all methods of its ancestors to become concrete.
  - Anonymous classes can also contain non-static fields, other non-static methods and even further non-static nested classes.
    - Anonymous classes have no name, therefor we can't formulate a call to a static member.
  - Code in anonymous classes can access and modify fields of the outer class, but it cannot modify locals of the enclosing method.
    - Locals of the enclosing method are effectively final for the anonymous class.
  - Anonymous classes can be defined as local classes, static nested classes or inner classes.
- Usage side of anonymous classes:
  - It is required to create an instance of the anonymous class directly with its definition!
  - As compile time type of that instance, we usually use the type of the UDT being extended or implemented.

Callbacks – Part 1

- Up to here, we have only dealt with code, that <u>we use explicitly</u>, e.g. we <u>call</u> own or 3rd party/JDK's methods.

- We can also program code, that is <u>called from other code</u>, e.g. from the <u>operating system</u> or the <u>JVM</u>!

- Consider following code, which tells the JVM to call the method *MyTimerTask.run()* to be called every 10s:

TimerTask
+ run() + cancel() : boolean + scheduledExecutionTime() : long

```java
// <Program.java>
import java.util.*:

public class Program {
        public static void main(String[] args) {
                class MyTimerTask extends TimerTask {
                        @Override
                        public void run() {
                                System.out.println("Invoked");
                        }
                }
                TimerTask timerTask = new MyTimerTask();
                Timer timer = new Timer(true);
                timer.scheduleAtFixedRate(timerTask, 0, 10_000);
                Thread.sleep(60_000);
                timer.cancel();
        }
}
```

Terminal

```
NicosMBP:src nico$ java Program
Invoked
Invoked
Invoked
Invoked
Invoked
Invoked
Invoked
NicosMBP:src nico$
```

- Since the method *MyTimerTask.run()* is <u>called back from the JVM</u>, it is <u>called call back method</u> or simply <u>"callback"</u>.

Callbacks – Part 2

- The classes *TimerTask* and *Timer* are Java's connection to the operating system's timer system.

- We can use those classes to get notifications about timer-events from the operating system.

- So, an event from the operating system signals, that something has happened.
  - *Timer* allows us to react on an event, esp. it allows us to react on periodically sent events from the operating system.
  - Instead, that our code "directly" reacts on such events, we register a *TimerTask*-object, that is called, when the event was emitted.
  - The *TimerTask*-object we use as callback is not directly called, instead it is invoked at a later point in time: when the event was emitted.

- The take away: a callback is an object/method, which is called "somewhen by the system".
  - When it is called is out of our control, we just provide the callback.

Callbacks – Part 3

- So called event-driven programming is another programming paradigm.
  - The idea is, that a program is not executed by imperative flow, but driven by events.
- The code, which we want to be called, when the event in question is emitted must be registered as callback.
  - The callback is executed at any point in future. I.e. the time the callback is registered is different from the time it is actually called!
  - We say, the callback is called asynchronously. – It means it is called asynchronously related to the time the callback was registered.
  - Events and callback are the basis of yet another programming paradigm: asynchronous programming.
  - Callbacks, i.e. objects, which are called when an event is emitted are usually called event handlers in Java.
- Event-driven programming means that code is invoked by own or external events, which are emitted asynchronously.
- Callbacks represent an own programming principle: the Hollywood principle.
  - The Hollywood principle says "Don't call us, we call you!".
  - In our case with the timer: "Please call me back every 10s, here is my number, i.e. the *timerTask* reference".

```
// Registers timerTask as event handler:
timer.scheduleAtFixedRate(timerTask, 0, 10_000);
```

Callbacks – Part 4

- One of Java's crucial applications of anonymous classes is to define callbacks in a simple way. Consider:

```
class MyTimerTask extends TimerTask {
	@Override
	public void run() {
		System.out.println("Invoked");
	}
}
TimerTask timerTask = new MyTimerTask();
Timer timer = new Timer(true);
timer.scheduleAtFixedRate(timerTask, 0, 10_000);
Thread.sleep(60_000);
timer.cancel();
```

```
Timer timer = new Timer(true);
timer.scheduleAtFixedRate(new TimerTask() {
	@Override
	public void run() {
		System.out.println("Invoked");
	}
}, 0, 10_000);
Thread.sleep(60_000);
timer.cancel();
```

  - As can be seen, we just pass the anonymous class-expression as argument to *Timer.scheduleAtFixedRate()*.
  - The code is functionally equivalent.

- Timer events with *TimerTask* are simple examples how to use anonymous classes as callbacks.
  - Callbacks are used in many other places is Java, not only as event handlers.
  - Callbacks are also used as objects transporting a piece of code to an algorithm.
    - An important example are *Comparator*s, which allow to control sorting algorithms.
  - As lambdas and method references together with *Stream*s, callbacks support functional programming as higher order functions.

- Callbacks can – of course – also be objects of top level classes!

Thank you!