Advanced programming for Java platform

Introduction

About course

- Petr Hnětynka
  - hnetynka@d3s.mff.cuni.cz
- http://d3s.mff.cuni.cz/teaching/vsjava/
- continuation of "Java (NPRG013)"
  - basic knowledge of Java is expected (in the scope of NPRG013)
- 2/2 Zk/Z

Exam/"Započet"

- exam
  - written test
    - as in the winter semester
- "zápočet"
  - home project
    - see the next slide
  - test in the lab
  - 3 homeworks
    - at least 150 points
  - attendance to the practicals
    - > 3 absences => at least 210 points from homeworks

"Zápočet"

- creating a project
  - agreeing a topic till Friday 22nd May 2019
    - by email
    - appropriately complex topic
    - non-trivially exploiting a covered technology
  - the project should be submitted till the end of June
    - the latest deadline – Tuesday 22nd September 2020
    - submission by email; only if it is necessary the project is shown personally

Course synopsis

- GUI
- in-depth view of the Java language
  - reflection API
  - generics, annotations
  - classLoaders, security
- distributed technologies: RMI,...
- component model JavaBeans
- JEE: Servlets, EJB, Spring,...
- JME: CLDC, MIDP, MEEP
- RTSJ
- other Java-based technologies: Java APIs for XML, JDBC, JMX,…
- other languages compiled to Java byte-code
- Android

Popularity

Feb 2020	Feb 2019	Change	Programming Language	Ratings	Change
1	1		Java	17.358%	+1.48%
2	2		C	16.766%	+4.34%
3	3		Python	9.345%	+1.77%
4	4		C++	6.264%	-1.28%
5	7	↑	C#	5.927%	+3.08%
6	5	↓	Visual Basic .NET	5.862%	-1.23%
7	6	↓	JavaScript	2.060%	-0.79%
8	8		PHP	2.018%	-0.25%
9	9		SQL	1.526%	-0.37%
10	20	⇈	Swift	1.460%	+0.54%

http://www.tiobe.com/tiobe_index

Worldwide, Feb 2020 compared to a year ago:

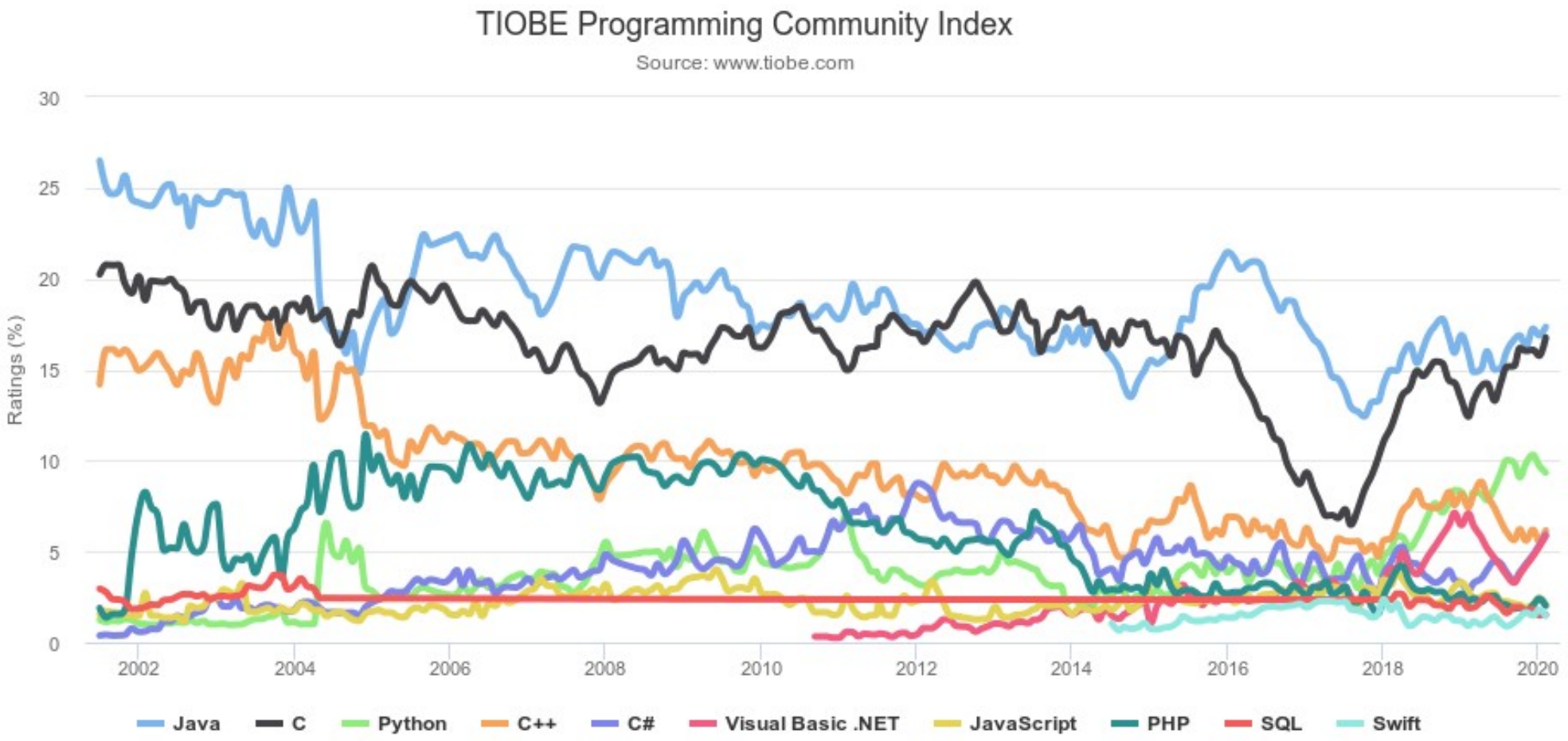
Rank	Change	Language	Share	Trend
1		Python	29.88 %	+4.1 %
2		Java	19.05 %	-1.8 %
3		Javascript	8.17 %	+0.1 %
4		C#	7.3 %	-0.1 %
5		PHP	6.15 %	-1.0 %
6		C/C++	5.2 %	-0.2 %
7		R	3.74 %	-0.2 %
8		Objective-C	2.42 %	-0.6 %
9		Swift	2.28 %	-0.2 %
10	↑	TypeScript	1.84 %	+0.3 %

http://pypl.github.io/PYPL.html

Rank	Language	Type	Score
1	Python		100.0
2	Java		96.3
3	C		94.4
4	C++		87.5
5	R		81.5
6	JavaScript		79.4
7	C#		74.5
8	Matlab		70.6
9	Swift		69.1
10	Go		68.0

https://spectrum.ieee.org/static/interactive-the-top-programming-languages-2018

Popularity



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Java

Type system

- strongly typed language
  - classes
  - primitive types (int, boolean, char,...)
- "everything" is in a class
- no global variables, functions,...
  - **static** methods and fields can seen as global elements

Test

```
public class InitTest {
  static int i = 1;
  { i+=2; };
  static { i++; };
  public static void main(String argv[]) {
    System.out.println(i);
    System.out.println(new InitTest().i);
  };
};
```

The program prints out:

a) 2 4
b) 1 3
c) 3 5
d) 4 4
e) cannot be compiled

Solution

- correct is a) 2 4

- { ..... } in the class body
  - initializer
  - executed when an instance is created
  - used for initialization of anonymous inner classes
- static { ..... }
  - static initializer
  - executed during class loading to VM
  - can access only static elements of the class

Test 2

```
public class InitTest {
  static int i = 1;
  { i+=2; };
  public InitTest() {
    System.out.println(i++);
  }
  static { i++; };
  public static void main(String argv[]) {
    System.out.println(i);
    System.out.println(new InitTest().i);
  };
};
```

Results:

a) 1 3 5
b) 2 3 5
c) 2 4 5

Solution of test 2

- correct us C) 2 4 5
- the initializer is executed before execution of a constructor
- first, a superclass is initialized
  - initializers and constructors

Exceptions and initializers

- initializers can throw only exceptions that are defined in constructors
  - there must be at least one constructor

- initializers of anonymous inner classes can throw any exceptions
  - the class is instantiated just once
  - no problem to catch/declare the exceptions

Static initializers

- have to terminate without an exception
  - otherwise cannot be compiled
- run in the order as in the source file
- cannot contain **return**
  - otherwise cannot be compiled

Visibility in classes

- is it possible to change element's visibility in children?
  - e.g.

```
class A { public void foo() {} }
class B extends A { private void foo() {} }
```

- visibility cannot be “restricted” but can be “increased”
- why
  - if it would be possible

```
class A { public void foo() {} }
class B extends A { private void foo() {} }
```

  - then the following code would be possible

```
A a = new B();
a.foo();
```

Type changes

- covariant change – from specific to generic
- contravariant – vice versa

- arrays in Java are covariant

```
Number[] numbers = new Number[3];
numbers[0] = new Integer(10);
numbers[1] = new Double(3.14);
numbers[2] = new Byte(0);

Integer[] myInts = {1, 2, 3, 4};
Number[] myNumbers = myInts;

Object obj = myNumbers;
```

- what would happen if we try this?

```
myNumbers[0] = 3.14;
```

Covariance

- **`myNumber[0] = 3.14;`**
  - can be compiled
  - exception at runtime

Reflection API

Overview

- Reflection
  - changes structure/state of objects
- Introspection
  - exploring a structure of objects

- allows
  - obtaining information about class, fields, methods
  - creating instances
  - calling methods
  - ...
- package `java.lang.reflect`
- class `java.lang.Class`

java.lang.Class<T>

- an instance of the **Class** class represents a class or interface in a running program
- primitive types are also represented as instance of the **Class** class
- it has no constructor
- instances created automatically during loading the class to JVM
  - classes are loaded to JVM just before their first usage
- since Java 5 – a generic type
  - T – the type of the class represented by this Class object
    - ex.: for **`String`** ~ **`Class<String>`**
    - if unknown, then **`Class<?>`**

java.lang.Class<T>

- obtaining instances of **Class**
  - `getClass()`
    - method of the Object class
    - returns the class of the object, on which it is called
  - literal **class** (it is an *expression* of the type *Class*)
    - `JmenoTridy.class`
    - the class for the given type
  - `Class.forName(String className)`
    - static method
    - returns the class with the given name
  - for primitive types
    - static filed TYPE of the wrapper classes
      - `Integer.TYPE`
    - literal `class`
      - `int.class`

java.lang.Class<T>

- the type after obtaining the instance

```
String s = "hello";
Class<String> clazz1 = s.getClass();

Class<String> clazz2 = String.class;

Class<Integer> clazz3 = int.class;
```

  - but

```
Class<?> clazz4 =
            Class.forName("mypackage.MyClass");
```

java.lang.Class<T>

- classes are loaded to JVM by a *classloader*
  - `java.lang.ClassLoader`
  - the standard classloader looks up classes in CLASSPATH
  - it is possible to create own classloader
  - `Class.forName(String className, boolean initialize, ClassLoader cl)`
    - loades a class with the given classloader and returns the instance of the class
  - `getClassLoader()`
    - a method of the Class class
    - returns a classloader, which loaded the class
      - *warning:* the type of an object is represented not only by the Class but also by a cloassloader that loaded the given class
        - in detail will be later

java.lang.Class<T>: methods

- `boolean isPrimitive()`
- `boolean isArray()`
- `boolean isInterface()`
- `boolean isEnum()`
- `boolean isAnnotation()`
  - tests whether the class represents a primitive type resp. array resp. interface resp. enum resp. annotation
- `boolean isInstance(Object o)`
  - tests whether the given object is an instance of the class
  - equivalent to the instanceof operator
- `boolean isAssignableFrom(Class<?> cls)`
  - tests whether the class/interface is the same as `cls` or a superclass/superinterface of `cls`
  - i.e. whether an object of the type cls can be assigned to a variable of the type, on which the method is called

java.lang.Class<T>: methods

- `String getName()`
  - returns name of the class (interface,...)
  - for primitive types returns their names
  - for an array returns a string beginning with with [chars (as much as the array has dimensions) and then identification of the element type
    Z..boolean, B..byte, C..char, D..double, F..float, I..int, J..long, S..short, Lclassname..class or interface

```
String.class.getName() // returns "java.lang.String"
byte.class.getName()   // returns  "byte"
(new Object[3]).getClass().getName()
     // returns   "[Ljava.lang.Object;"
(new int[3][4][5][6][7][8][9]).getClass().getName()
     // returns   "[[[[[[[I"
```

java.lang.Class<T>: methods

- `Package getPackage()`
  - returns the package in which the class is defined
  - java.lang.Package
    - information about the package
- `Class<? super T> getSuperclass()`
  - returns the super class
  - returns null for the Object class, primitive types and interfaces
- `Class<?>[] getInterfaces()`
  - returns all implemented interfaces
  - if the class does not implement any interface, it returns an array with 0 elements
  - for primitive types it also an array with 0 elements

java.lang.Class<T>: methods

- `Method[] getMethods()`
  - returns all methods of the class (public)
- `Field[] getFields()`
  - returns all fields of the class (public)
- `Constructor<?>[] getConstructors()`
  - returns all constructors of the class (public)
- `Method[] getDeclaredMethods()`
- `Fields[] getDeclaredFields()`
- `Constructor<?>[] getDeclaredConstructors()`
  - returns all declared methods/fields/constructors of the class
    - it does not return inherited elements

java.lang.Class<T>: methods

- `Field getField(String name)`
- `Field getDeclaredField(String name)`
  - returns a field of the given name
- `Method getMethod(String name, Class<?>... paramTypes)`
- `Method getDeclaredMethod(String name, Class<?>... paramTypes)`
  - returns a method of the given name and given types of parameters
- `Constructor<T> getConstructor(Class<?>... paramTypes)`
- `Constructor<T> getDeclaredConstructor(Class<?>... paramTypes)`
  - returns a constructor of the given types of parameters

java.lang.Class<T>: methods

- `Class<?> getDeclaringClass()`
  - returns a class or interface in which the class/interface is declared
  - for inner classes
- `Class<?>[] getClasses()`
  - returns all classes/interfaces declared in the class or superclasses
- `Class<?>[] getDeclaredClasses()`
  - returns all classes/interfaces declared in the class
- `Class<?> getComponentType()`
  - returns a type of the array elements
  - for non-arrays, it returns null

java.lang.Class<T>: methods

- `public URL getResource(String name)`
- `public InputStream getResourceAsStream(String name)`
  - reads a resource
    - images, ..., anything
  - data are loaded by a classloader ==> loading by the same rules as loading classes
  - a name of the resource ~ hierarchical name as for classes
    - dots are replaced with slashes `'/'`
- `T cast(Object o)`
  - since Java 5
  - in <=JDK 1.4 would have no meaning
- `T[] getEnumConstants()`
  - returns an array with values of the enum
    - if the class does not represent an enum, it returns null

java.lang.Class<T>: instance

- `T newInstance()`
  - creates a new instance of the class
  - a parameter-less constructor is used
    - it is the same as usage of new AClass()
  - **deprecated** since Java 9
    - use `getDeclaredConstructor().newInstance()`

- creating new instance of the class using different constructors
  - the class `java.lang.reflect.Constructor<T>`

Modifiers

- `int getModifiers()`
  - method of java.lang.Class
  - returns modifiers encoded in an integer

- `java.lang.reflect.Modifiers`
  - decoding the integer with modifiers
  - static methods
    - `boolean isPublic(int mod)`
    - `boolean isStatic(int mod)`
    - `boolean isSynchronized(int mod)`
    - `....`
    - `void toString(int mod)`
      - returns a readable string with modifiers

java.lang.reflect.Field

- information about fields
- accessing fields

- methods
  - `String getName()`
    - name of the fields
  - `Class<?> getType()`
    - type
  - `int getModifiers()`
    - modifiers
  - `Class<?> getDeclaringClass()`
    - in which class it is declared

java.lang.reflect.Field

- obtaining value of the field
  - `Object get(Object obj)`
    - returns a value of the field of the object obj
    - for primitive type fields, the value is returned in the corresponding wrapper type
  - `boolean getBoolean(Object obj)`
    - returns value of the boolean field in the object obj
  - `int getInt(Object obj)`
    - returns value of the int field in the object obj
  - ...
- setting value of the field
  - `void set(Object obj, Object value)`
    - sets the value to the field in the object obj
  - `void setInt(Object obj, int v)`
  - `void setBoolean(Object obj, boolean b)`
  - ....

java.lang.reflect.Method

- `String getName()`
- `Class getDeclaringClass()`
- `int getModifiers()`
- `Class<?> getReturnType()`
  - returning type of the method
- `Class<?>[] getExceptionTypes()`
  - array of types of exceptions the method can throw
- `Class<?>[] getParameterTypes`
  - returns an array with types of the parameters
  - in the declared order

java.lang.reflect.Method

- `Object invoke(Object obj, Object... params)`
  - calls the method on the object obj
  - params – values for parameters for the call
    - for methods with no parameters, the params can be null or zero-length array
    - parameters in the declared order
    - values of primitive types in the corresponding wrapper
  - returns returning value of the method call
    - values of primitive types in the corresponding wrapper

java.lang.reflect.Constructor<T>

- `String getName()`
- `Class<T> getDeclaringClass()`
- `int getModifiers()`
- `Class<?>[] getExceptionTypes()`
- `Class<?>[] getParameterTypes()`
- `Object newInstance(Object... params)`
  - creates new instance of the class
  - the same rules for the params like for the method `invoke()`

java.lang.reflect.Executable

- since Java 8
- `Method` and `Constructor` extends `Executable`
- new methods
  - `public int getParameterCount()`
    - number of formal parameters
  - `public Parameter[] getParameters()`
    - parameters
  - ...

- `Parameter`
  - since Java 8
  - `public String getName()`
    - name of the parameter
      - in Java <= 7 the parameter's name cannot be obtained

java.lang.reflect.Array

- static methods for accessing arrays
- `Object newInstance(Class<?> componentType, int length)`
  - creates a single-dimension array
- `Object newInstance(Class<?> componentType, int[] dimensions)`
  - creates a multi-dimension array
- `Object get(Object array, int index)`
- `int getInt(Object array, int index)`
- `...`
- `void set(Object array, int index, Object val)`
- `void setInt(Object array, int index, int val)`
- `...`

Reflection vs. generics

- Introspection is performed a runtime
  - be careful with the *type erasure*

```
class MethodTrouble<T> {
    void lookup(T value) {}
}
```

```
Class<?> c = (new MethodTrouble<Integer>()).getClass();
Method m = c.getMethod("lookup", Integer.class);
```

Reflection vs. generics

- `Class` implements the interface `GenericDeclaration`:
  - `TypeVariable<?>[] getTypeParameters()`
    - returns an array with generic parameters declared by the class
      - is it possible to obtain
        - upper bound (***`T extends something`***)
        - declaring item
      - warning – lower-bound (***`T super something`***) cannot be specified for types!

Annotations

- `Class` implements the `AnnotatedElement` interface
  - which is also implemented by the classes Field, Method, Package

  - `Annotation[] getAnnotations()`
    - returns all annotations
  - `Annotation[] getDeclaredAnnotations()`
    - returns all annotations declared on the given class; it ignores inherited annotations
  - `<T extends Annotation> T getAnnotation(Class<T> annotationType)`
    - returns an annotation of the given type (e.g. Override.class) declared on the class or null

Reflection and modules

- `Class<?> Class.forName(Module m, String name)`
- method on Class
  - `Module getModule()`
- `java.lang.Module`
  - `String getName()`
  - `Set<String> getPackages()`
  - `ModuleDescriptor getDescriptor()`
  - …
  - in more detail later

What can be done with it?

- Plugins
  - Dynamic loading, instantiation
  - Interface adaptation
- Processing annotations at runtime
  - see EJB, Spring, Hibernate
- Patching/debugging code
  - accessing non-public fields (see *Field.setAccesible(true)*),
  - Runtime code generation
- Proxies

java.lang.reflect.Proxy

- creating dynamic proxy classes
  - a class implementing a given interface and it calls methods from a different object (typically with an incompatible interface)
- `static Object newProxyInstance(ClassLoader loader, Class<?>[] interfaces, InvocationHandler h)`
  - interfaces – an array of interfaces to be implemented by the proxy
  - h – an object responsible for calling the methods
- InvocationHandler
  - the interface with the single method
  - `Object invoke(Object proxy, Method method, Object[] args)`

java.lang.reflect.Proxy

- example

```
InvocationHandler handler = new
                            MyInvocationHandler(...);

Foo f = (Foo)
Proxy.newProxyInstance(Foo.class.getClassLoader(),
                       new Class[] { Foo.class }, handler);
```

Plugins – example

```
interface Plugin {
  void foo();
}

class P1 implements Plugin {
  public void foo() {…}
}
```

Plugins – example (cont.)

```
class Main {
  private Plugin[] initPlugins(String[] namesOfPluginsClasses){
    ArrayList<Plugin> ps = new ArrayList<>();
    Class pluginIface = Plugin.class;
    for (String name : namesOfPluginClasses) {
       Class cls = Class.forName(name);
       if (cls.isArray() || cls.isInterface() ||
                  cls.isPrimitive() || ...) {  // report error
         continue;
       }
       if (!pluginIface.isAssignableFrom(cls)) {
         //report error
         continue;
       }
       ps.add(cls.newInstance());
    }
    return ps.toArray(new Plugin [ps.size()]);
  }
...
```