Technische Hochschule Rosenheim

Modul - Fortgeschrittene Programmierkonzepte

Bachelor Informatik

06 - Reflection und Annotations

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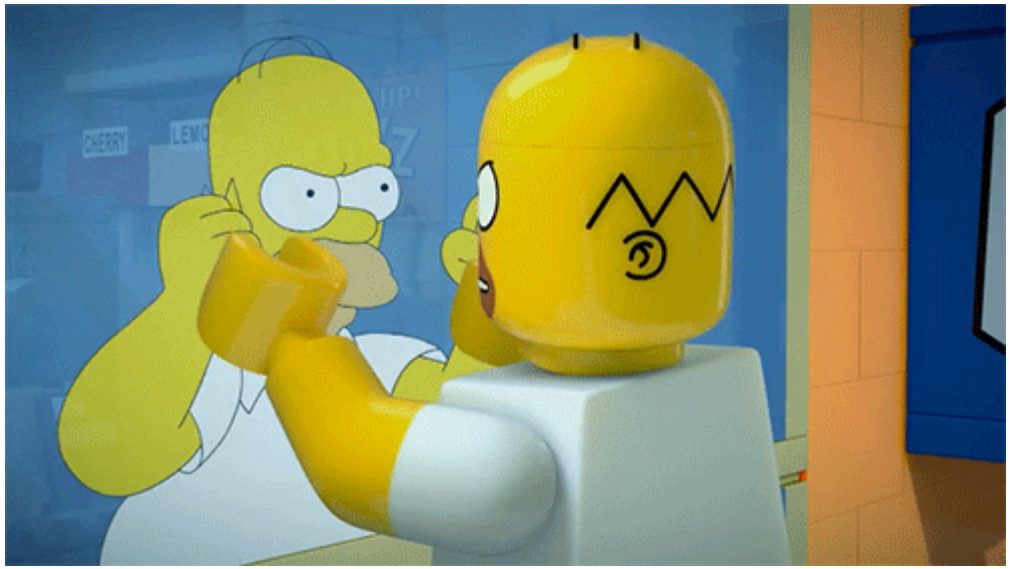
Agenda for today



- `java.lang.Class<T>`: your ticket to reflection
- Messing with Objects
- Basic Java beans (a simple plugin architecture)
- Annotations

Reflection

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Type introspection is the ability of programming languages to determine the type (or its properties) of an arbitrary object at runtime.

Java takes this concept one step further with *reflection*, allowing not only to determine the type at runtime, but also modifying it.

At its core, reflection builds on `java.lang.Class`, a generic class that *is* the definition of classes.

Note that most of the classes we will be using when dealing with reflection are in the package `java.lang.reflection` (package summary), and (almost) none of them have public constructors -- the JVM will take care of the instantiation.

Classes

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There are different ways to get to the class object of a Class:

```
// at compile time
Class<String> klass1 = String.class;

// or at runtime
Class<? extends String> klass2 = "Hello, World!".getClass();
Class<?> klass3 = Class.forName("java.lang.String");
Class<String> klass4 = (Class<String>) new String().getClass();

System.out.println(klass1.toString());  // java.lang.String
System.out.println(klass2.toString());  // ditto...
System.out.println(klass3.toString());
System.out.println(klass4.toString());

klass1.getName();          // java.lang.String
klass1.getSimpleName();    // String
```

Class: Class

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As a note ...

- use `Class<T>` to get the class name if known at compile time (or use an unchecked cast at runtime)
- use the `?` (wildcard) and appropriate bounds for *any* type.

So what can you do with a `Class<?>` object?

Basic Type Information

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You can use `Class<?>` object to get basic type information:

```
// all of these will return true
int.class.isPrimitive();

String[].class.isArray();

Comparable.class.isInterface();

(new Object() {})
    .getClass()
    .isAnonymousClass();          // also: local and member classes

Deprecated.class.isAnnotation();  // we will talk about those later
```

As you can see, even primitive type like `int` or `float` have class objects (which are, by the way, different from their wrapper types `Integer.class` etc.!).

Type Internals

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You can get even more ...

```
// family affairs...
String.class.getSuperClass();    // Object.class

// constructors
String.class.getConstructors();  // returns Constructor<String>[]

// public methods
String.class.getMethod("charAt", int.class);
String.class.getMethods();       // returns Method[]

// public fields (attributes)
// Comparator<String>
String.class.getField("CASE_INSENSITIVE_ORDER");
String.class.getFields();        // returns Field[]

// public annotations (more on this later)
String.class.getAnnotation(Deprecated.class);          // null...
String.class.getAnnotationsByType(Deprecated.class);   // []
String.class.getAnnotations();  // returns Annotation[]
```

Some Remarks

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These methods may throw `NoSuch{Method,Field}Exception`s and `SecurityException`s (more on security later).

You can distinguish between *declared* fields (methods, ...), and "just" fields: `.getFields()` (and `.getMethods()` etc.) will return *the public* fields of an object, including those inherited by base classes.

Use `.getDeclaredFields()` (and `.getDeclaredMethods()` etc.) to retrieve *all* fields declared in this particular class.

Object Instantiation

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As you can see, you can also query for *constructors* of a class. This is the base for creating new instances based on class definitions:

```
Class<?> klass = "".getClass();
String magic = (String) klass.newInstance();  // unchecked cast...
```

Sticking with the example of strings, the documentation tells us that there exist non-default constructors. Consider for example the `String(byte[] bytes)` constructor:

Object Instantiation

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```
Constructor<String> cons = (Constructor<String>)
    String.class.getConstructor(byte[].class);

String crazy = cons.newInstance(new byte[] {1, 2, 3, 4});
```

Note that this may trigger quite a few exceptions: `InstantiationException`, `IllegalAccessException`, `IllegalArgumentException`, `InvocationTargetException`, all of which make sense if you extrapolate their meaning from the name.

Messing with Objects

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Modifying Fields (Attributes)

Remember Rumpelstiltskin?

In short: A very ambitious father claimed his daughter could produce gold. Put under pressure by the king, she cuts a deal with an imp: it spins the gold and in return she would sacrifice her first child --

unless she could guess the imp's name!

Objects

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Ok, here's the mean imp and the poor daughter:

```
class Imp {
    private String name = "Rumpelstiltskin";
    boolean guess(String guess) {
        return guess.equals(name);
    }
}
```

```
class Daughter {
    public static void main(String... args) {
        Imp imp = new Imp();

        // to save your child...
        imp.guess(???);
    }
}
```

More about it ...

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Since `Imp.name` is private, the imp feels safe (it's dancing around the fire pit...). But can we help the daugher save her firstborn?

Yes, we can!

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Using reflection, we will sneak through the imp's "head" to find the string variable that encodes the name.

```
Imp imp = new Imp();
String oracle = null;
// get all fields
for (Field f : imp.getClass().getDeclaredFields()) {

    f.setAccessible(true);  // oops, you said private? :-)

    // looking for private String
    if (Modifier.isPrivate(f.getModifiers())
            && f.getType() == String.class) {
        oracle = (String) f.get(imp);  // heureka!
    }
}
imp.guess(oracle);  // true :-)
```

Alternatively

```
Imp imp = new Imp();

for (Field f : imp.getClass().getDeclaredFields()) {
    f.setAccessible(true);
    if (Modifier.isPrivate(f.getModifiers())
        && f.getType() == String.class) {
        f.set(imp, "Pinocchio");  // oops :-)
    }
}

imp.guess("Pinocchio");  // true :-)
```

The `Field` class allows us to retrieve and modify both the modifiers and the values of fields (given an instance).

Calling Functions

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Similar to accessing and modifying fields, you can enumerate and invoke methods. Sticking with the imp above, what if the imp's name were well-known, but nobody knew how to ask for a guess?

```
class WeirdImp {
    static final String name = "Rumpelstiltskin";
    private boolean saewlkhasdfwds(String slaskdjh) {
        return name.equals(slaskdjh);
    }
}
```

Accessability

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This time, the `name` is well known, but the guessing function is hidden. Again, reflection to the rescue.

```
WeirdImp weirdo = new WeirdImp();
for (Method m : weirdo.getClass().getDeclaredMethods()) {
    m.setAccessible(true);

    // ...returns boolean?
    if (m.getReturnType() == boolean.class
            // ...has one arg?
            && m.getParameterCount() == 1
            // which is String?
            && m.getParameterTypes()[0] == String.class) {
        System.out.println(m.invoke(weirdo, Weirdo.name));
    }
}
```

Basic Java Beans

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Reflection can be used to facilitate an architecture where code is dynamically loaded at runtime. This is often called a *plugin mechanism*, and Java Beans have been around for quite a long time.

Consider this simple example: We want to have a game loader that can load arbitrary text-based games which are provided as a third party `.jar` file.

```
package reflection;
public interface TextBasedGame {
    void run(InputStream in, PrintStream out) throws IOException;
}
```

Beans Example

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A simple *parrot* (echoing) game could be:

```
package reflection.games;
public class Parrot implements TextBasedGame {
    @Override
    public void run(InputStream in, PrintStream out)
        throws IOException {

        BufferedReader reader = new BufferedReader(
            new InputStreamReader(in));
        out.println("Welcome to parrot. Please say something");

        String line;
        while ((line = reader.readLine()) != null
            && line.length() > 0) {
            out.println("You said: " + line);
        }
        out.println("Bye!");
    }
}
```

Load Class

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These games all implement the `TextBasedGame` interface, and their `.class` files can be packaged into a jar.

Later, if you know the location of the jar file, you can load classes by-name:

```
package reflection;
public class TextGameLoader {
    public static void main(String... args) throws Exception {

        // load classes from jar file
        URL url = new URL("jar:file:/...hsro-inf-fpk/example/games.jar!/");
        URLClassLoader cl = URLClassLoader.newInstance(new URL[] {url});

        // you can play "Addition" or "Parrot"
        final String choice = "Parrot";
        TextBasedGame g = (TextBasedGame) cl.loadClass
            ("reflection.games." + choice)
            .newInstance();
        g.run(System.in, System.out);
    }
}
```

Security

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The previous sections showed clearly how powerful the tools of reflection are. Naturally, security is a concern: what if someone loads your jars, enumerates all classes, and then tries to steal passwords from a user?

This has indeed been done, and is the reason why Java was historically considered insecure or even unsafe to use. However, newer versions of Java have a sophisticated system of permissions and security settings that can limit or prevent reflection (and other critical functionality).

Two things that do *not* work, at least out of the box:

- While you can do a forced write on `final` *fields*, this typically does not affect the code at runtime, since the values are already bound at compiletime.
- It is impossible to swap out *methods* since class definitions are read-only and read-once. If you wanted to facilitate that, you would have to write your own class loader.

Object Comparison

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One last word regarding reflection and object comparison. As you know, we distinguish two types of equality: reference and content-based equality.

```
class K {
    K(String s) {
        this.s = s;
    }
}

int a = 1;
int b = 1;

a == b;  // true: for primitive types, the values are compared

K k1 = new K("Hans");
K k2 = new K("Hans");

k1 == k2;        // false: they point to different memory
k1.equals(k2);   // ???
```

equals()-Method

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If you don't overwrite the `.equals` method in your class, the default version `Object.equals` will check for reference equality. If you overwrite it, you need to make sure to

- test for `null`
- test for reference equality (same memory?)
- test for same *type*
- call `super.equals()`, if it was overwritten there
- compare all attributes

equals()-Method

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Consider this implementation of `equals`:

```
public boolean equals(Object o) {
    if (o == null) return false;
    if (o == this) return true;   // same memory
    // version A
    if (!this.getClass().equals(o.getClass()))
        return false;
    // version B
    if (this.getClass() != o.getClass())
        return false;
    // version C
    if (!(o instanceof K))
        return false;
    if (!super.equals(o))
        return false;
    // now compare attributes
    return this.s.equals(((K) o).s);
}
```

What works?

Explanation

Here's the question: Which of the versions A, B or C are correct ways to test if the *types* of the two objects match?

A) is correct, since we compare both runtime classes with `.equals`.

B) is correct, since the class objects are shared among all instances (and parametrized generics; recall type erasure).

C) is however *incorrect*: the `instanceof` operator would also return `true` if there is a match on an interface of derived class.

Annotations

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Annotations are *meta-information*, they can be attached to classes, methods or fields, and can be read by the compiler or using reflection at runtime.

They are denoted using the `@` character, for example `@Override`.

Defining Annotations

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Annotations are similar to interfaces: both as in syntax and as in a method or field can have multiple annotations.

```
public @interface Fixed {
    String author() ;
    String date() ;
    String bugsFixed() default "" ;
}
```

This defines the annotation `@Fixed(...)` with three arguments; the last one is optional and defaults to the empty string.

```
@Fixed(author="mustermann", date="2011-11-11")
void method() { ... }
```

Meta-Annotations

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Even annotations can be annotated. *Meta annotations* define where and how annotations can be used.

- `@Target({ElementType.FIELD, ElementType.METHOD})`: Use this to limit your custom annotation to fields or methods.
- `@Retention(RetentionPolicy.{RUNTIME,CLASS,SOURCE)}`: This controls if the annotation is available at runtime, in the class file, or only in the source code.
- `@Inherited`: Use this to make an annotation to be passed on to deriving classes.

Method Annotations

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In general, there are *marker anotations* (e.g. `@Deprecated`) without arguments, *value annotations* (e.g. `@SuppressWarnings("...")`) that take exactly one value, and more sophisticated annotations (e.g. `@Fixed(...)` above).

```
class K {
    @Override
    public boolean equals(Object o) {
        // ...
    }
    @Deprecated
    public void useSomethingElseNow() {
        // ...
    }
    @SuppressWarnings("unchecked")
    public void nastyCasts() {

    }
}
```

Marker Annotations

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What are they good for?

- `@Override` is used to signal the intent of overwriting; results in compile error if its actually no overwrite (e.g. `@Override public boolean equals(K k)`)
- `@Deprecated` marks a method not to be used anymore; it might be removed in the future.
- `@SuppressWarnings(...)` turns off certain compiler warnings

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Type (Attribute) Annotations

`@NonNull`: The compiler can determine cases where a code path might receive a null value, without ever having to debug a `NullPointerException`.

`@ReadOnly`: The compiler will flag any attempt to change the object.

`@Regex`: Provides compile-time verification that a `String` intended to be used as a regular expression is a properly formatted regular expression.

`@Tainted` and `@Untainted`: Identity types of data that should not be used together, such as remote user input being used in system commands, or sensitive information in log streams.

```
abstract void method(@NonNull String value, @Regex re);
```

Annotations: JUnit5

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The new JUnit5 test drivers inspect test classes for certain annotations.

```
class MyTest {
    BufferedReader reader;

    @BeforeAll
    void setUp() {
        reader = new BufferedReader();  // ...
    }

    @Test
    void testSomeClass() {
        // ...
    }
}
```

Most of the time, you will get around with `@BeforeAll`, `@AfterAll` and `@Test`; see this complete list of annotations.

Annotations: Gson by Google

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Gson by Google helps with de/serializing objects (see today's assignment).

It allows you to map between JSON and Java objects:

```
class Klass {
    private int value1 = 1;
    private String value2 = "abc";
    @SerializedName("odd-name") private String oddName = "1337";
    private transient int value3 = 3;  // will be excluded

    Klass() {
        // default constructor (required)
    }
}
```

How to use it?

```
// Serialization
Klass obj = new Klass();
Gson gson = new Gson();
String json = gson.toJson(obj);
// ==> json is {"value1":1,"value2":"abc","odd-name": "1337"}

// Deserialization
Klass obj2 = gson.fromJson(json, Klass.class);
// ==> obj2 is just like obj
```

Annotations: Butterknife

Butterknife: GUI bindings for Android ridiculously simplified

```
class ExampleActivity extends Activity {
    @BindView(R.id.title) TextView title;
    @BindView(R.id.subtitle) TextView subtitle;
    @BindView(R.id.footer) TextView footer;

    @Override public void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.simple_activity);
        ButterKnife.bind(this);
        // TODO Use fields...
    }
}
```

Annotations: Retrofit

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Retrofit: consume REST interfaces without any pain

```
public interface GitHubService {
  @GET("users/{user}/repos")
  Call<List<Repo>> listRepos(@Path("user") String user);
}

Retrofit retrofit = new Retrofit.Builder()
    .baseUrl("https://api.github.com/")
    .build();

GitHubService service = retrofit.create(GitHubService.class);

Call<List<Repo>> repos = service.listRepos("octocat");
```

Summary

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Lessons learned today:

- Reflections
  - Classes, Methods, Attributes
  - Security
- Annotations
- Frameworks
  - Butterknofe
  - GSON
  - Retrofit

Final Thought!