



Java and C# in depth

Carlo A. Furia, Marco Piccioni, Bertrand Meyer

Java: reflection



Introductory detour: quines

Basic reflection

- Built-in features
- Introspection
- Reflective method invocation

Dynamic proxies

Reflective code-generation

What's reflection?



A language feature that enables a program to examine itself at runtime and possibly change its behavior accordingly

Reflection allows inspection of classes, interfaces, fields and methods at runtime without knowing their names at compile time

It also allows object creation and method invocation

The usage of **metadata** is the key to reflection

What's reflection good for?



Consider an application that uses two different classes X and Y interchangeably to perform similar operations

Without reflection, the application might be hard-coded to call method names of class X and class Y

Using reflection, the application can invoke methods in classes X and Y “discovering” them at runtime

Software testing uses reflection a lot (mock objects)

More applications of Reflection at the end of the lecture



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Introductory detour: quines

An introductory detour: quines



A quine is a program that outputs its own source code

- named after the philosopher Willard Van Orman Quine and his studies of self-reference
- it is an example of reflection

In pseudocode, the basic algorithm for a quine is:

Print the following sentence twice, the second time between quotes.

“Print the following sentence twice, the second time between quotes.”

Can you write a quine in Java?

Java quine



- From: http://www.nyx.net/~gthompso/self_java.txt
- Author: Bertram Felgenhauer

```
class S{
public static void main(String[]a) {
    String s="class S{public static void
main(String[]a){String s=;char c=34;
System.out.println(s.substring(0,52)+c+s+c+s
.substring(52));}}";
    char c=34;
    System.out.println(s.substring(0,52)+c+s+c+s
.substring(52));
}}
```



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Basic mechanisms for reflection

Normal vs. reflective at a glance

Creating an instance of **MyClass** and invoking public method **myMethod** is normally straightforward:

```
MyClass o = new MyClass(); o.myMethod();
```

Reflection makes things a bit harder:

```
Class<?> c = Class.forName("mypkg.MyClass"); //1  
Object o = c.newInstance(); //2  
//if the type is known statically we can cast  
MyClass o = (MyClass)c.newInstance(); //2bis  
//2nd argument: formal arg. list for myMethod  
Method m=c.getMethod("myMethod", (Class<?>)null); //3  
//2nd argument: actual arg. list to invoke myMethod  
m.invoke(o, (Object[]) null); //4
```

Little quiz: methods with parameters



Let's assume that `myMethod` takes a `String` and an `int`:

```
MyClass o = new MyClass(); o.myMethod("x", 1);
```

How does the reflective code change?

```
Class<?> c = Class.forName("mypkg.MyClass");
```

```
Object o = c.newInstance();
```

```
//2nd argument: formal arg. list for myMethod
```

```
Method m=c.getMethod("myMethod", //what here?);
```

```
//2nd argument: actual arg. list to invoke myMethod
```

```
m.invoke(o, //what here?);
```

Little quiz: methods with parameters



Let's assume that `myMethod` takes a `String` and an `int`:

```
MyClass o = new MyClass(); o.myMethod("x", 1);
```

How does the reflective code change?

```
Class<?> c = Class.forName("mypkg.MyClass");
```

```
Object o = c.newInstance();
```

```
//2nd argument: formal arg. list for myMethod
```

```
Method m=c.getMethod("myMethod", String.class,  
    int.class);
```

```
//2nd argument: actual arg. list to invoke myMethod
```

```
m.invoke(o, new Object[]{new String("x"),1});
```

Exceptions thrown by reflective code



```
try{
Class<?> c = Class.forName("mypkg.MyClass"); //1
Object o = c.newInstance(); //2
Method m=c.getMethod("myMethod", (Class<?>) null); //3
m.invoke(o, (Object[]) null); //4}
//these are only the checked exceptions thrown
catch {ClassNotFoundException e} {/////thrown by 1}
catch {InstantiationException e} {//thrown by 2}
catch {IllegalAccessException e} {//thrown by 2,4}
catch {NoSuchMethodException e} {//thrown by 3}
catch {IllegalArgumentException e} {//thrown by 4}
catch {InvocationTargetException e} {//thrown by 4}
```

Some unchecked exceptions and errors are also thrown...

Built-in reflection



Operator `instanceof`

- example: overriding `equals()`

```
public boolean equals(Object obj) {  
    // Querying for a type at runtime  
    if (!(obj instanceof IntendedType) {  
        return false;  
    }  
    ...  
}
```

Getting a **Class** object



- `java.lang.Class<T>` is the entry point

- represents the meta-info for classes

- How can I get a Class object?

- from an object reference

```
Class<?> c1 = myObj.getClass();
```

- from any type (including primitive types)

```
Class<?> c2 = int.class;
```

- from a primitive type, through the wrapper

```
Class<?> c3 = Integer.TYPE;
```

- from a (fully-qualified) class name

```
Class<?> c4 = Class.forName("ch.ethz.inf.se.java.reflect.myClassName");
```

Introspecting a class



Class objects provide information about:

- Modifiers: `int getModifiers()`
 - access (visibility) modifiers: `abstract`, `public`, `static`, `final`, ... encoded as integers
 - Tip: use static method `Modifier.toString(int mod)` to get a textual representation
- Generic type parameters:
`TypeVariable<Class<?>>[] getTypeParameters()`
- Implemented interfaces: `Class[] getInterfaces()`
- Inheritance hierarchy: `Class[] getClasses()`
- Annotations: `Annotation[] getAnnotations()`

Introspecting public class members



Class objects provide information about public members:

- Fields:

```
Field[] getFields()
```

```
Field getField(String fieldName)
```

- Methods:

```
Method[] getMethods()
```

```
Method getMethod(String methodName,  
Class<?>...paramTypes)
```

- Constructors:

```
Constructor<?>[] getConstructors()
```

```
Constructor<?> getConstructor(String  
constructorName, Class<?>...paramTypes)
```

Introspecting all class members



- Fields:

```
Field[] getDeclaredFields()
```

```
Field getDeclaredField(String fieldName)
```

- Methods:

```
Method[] getDeclaredMethods()
```

```
Method getDeclaredMethod(String methodName,  
Class<?>...paramTypes)
```

- Constructors:

```
Constructor<?>[] getDeclaredConstructors()
```

```
Constructor<?>
```

```
getDeclaredConstructor(Class<?>...paramTypes)
```

To make a non-visible field accessible via reflection, invoke:

```
f.setAccessible(true) //what's the type of f?
```



- Method `setAccessible(boolean flag)` in classes `Field` and `Method` toggles runtime access checking
- The security manager of the JVM can disable `setAccessible` altogether
- The `default` security manager allows `setAccessible` on members of classes loaded by the same class loader as the caller



Besides the already mentioned checked exceptions, reflection may trigger the following un-checked exceptions and errors:

- **SecurityException**
- **NullPointerException**
- **ExceptionInInitializerError**
- **LinkageError**

While we don't have to handle these exceptions and errors, we do have to handle the checked ones, bloating the code even more



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Dynamic proxies



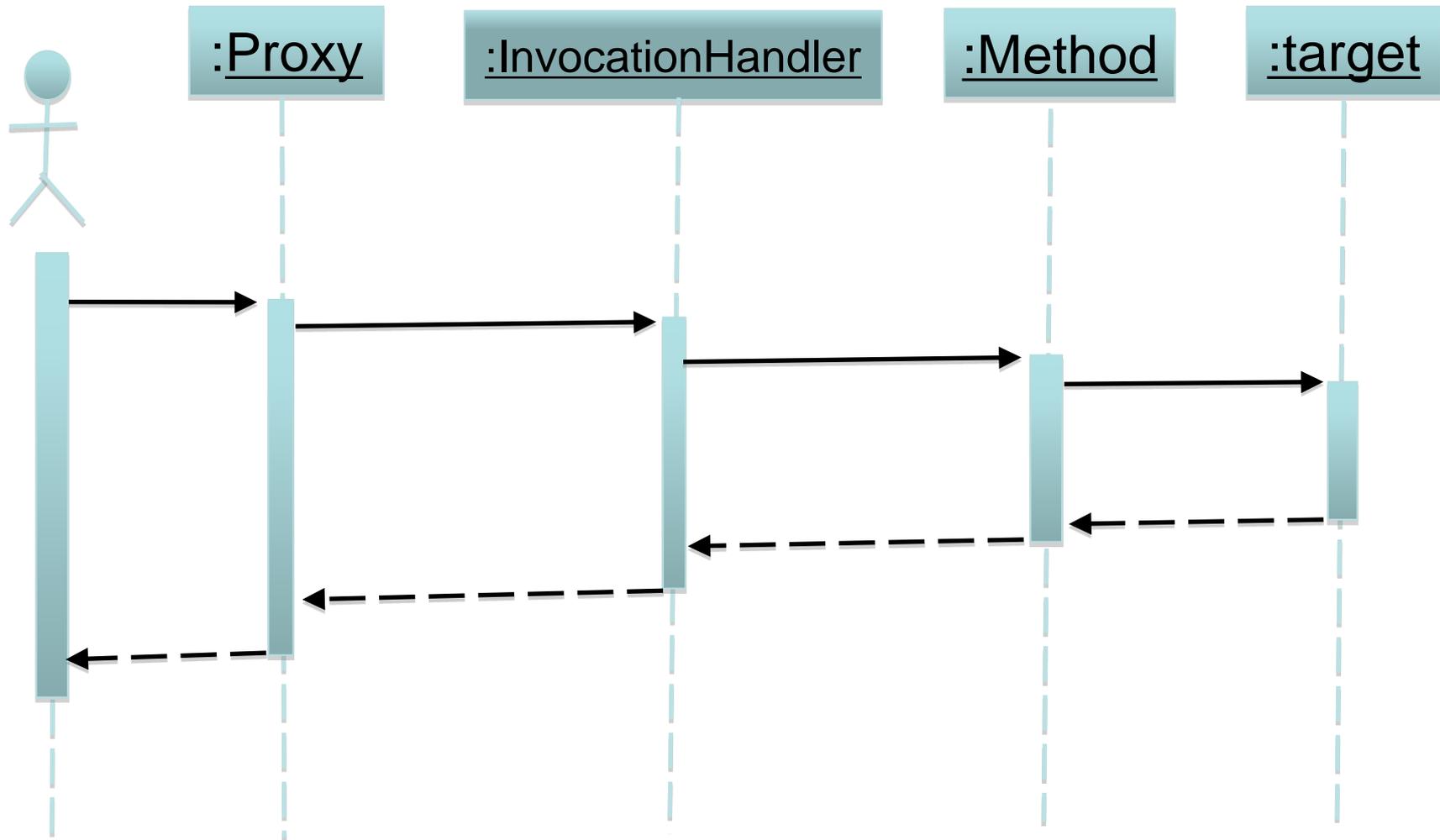
The idea comes from the Proxy design pattern (GoF):

Allows for object level access control by acting as a pass through entity or a placeholder object

Dynamically created classes that implement some interfaces

- Typical usage of dynamic proxy objects: intercept calls to objects of different classes implementing the same interfaces
- Standard Java approach to Aspect Oriented Programming (AOP): cross-cutting concerns are centralized

Proxy sequence diagram



java.lang.reflect.Proxy

Java's dynamic proxy factory:

- The factory produces objects of classes extending class **Proxy**
- They also implement the proxied interfaces and associate an **InvocationHandler** object

Object newInstance(ClassLoader loader, Class<?>[] interfaces, InvocationHandler h)

- **InvocationHandler** is an interface to wrap objects providing methods that can handle method calls to proxy instances
- The handler object holds a reference to the target object



Example: a proxy for shapes

```
public interface IDrawable {  
    public void draw();  
}
```

```
public class Shape implements IDrawable {  
    public void draw() {  
        //draw a shape  
    }  
    ...  
}
```



A factory for shapes

The clients get an `IDrawable` object:

```
public class DrawablesFactory{

public static IDrawable getDrawable() {
    Shape s = new Shape();
    return Proxy.newProxyInstance(
        this.getClass().getClassLoader(),
        new Class[]{IDrawable.class},
        new CustomInvocationHandler(s));
}
}
```

Sample invocation handler



```
class CustomInvocationHandler
    implements InvocationHandler{
private proxied;
public CustomInvocationHandler(Shape s) {
    proxied = s; }

public Object invoke(Object proxy, Method m,
Object[] args) throws Throwable{
    // Pre-processing here
    Object result = m.invoke(proxied, args);
    // Post-processing here
    return result;
}
}
```

Proxy usage: example

```
/* If the client does not know which
   specific type comes from the factory */
IDrawable s =
    DrawablesFactory.getDrawable();
/* If the client wants to use other
   features of Shape as well*/
Shape s = (Shape)
    DrawablesFactory.getDrawable();

s.draw();
```



- You can only proxy for an interface, not for a class
- Use handlers to process requests
- `instanceof` can be used on proxy objects
- Casting works with proxy objects



What is a Class Loader

- For every class in the system, the JVM maintains a copy of the class code in the form of an instance of `java.lang.Class`
 - the `class` attribute of any `Object` returns it
- Every class is loaded in the JVM by an instance of `java.lang.ClassLoader`
 - reflection is really built-in in the JVM
- Within the JVM, a class is uniquely defined by:
 - its fully-qualified name (i.e., including the package name)
 - **and** the instance of the class loader that loaded it
- User-defined class loaders may make different usages of the same class incompatible (if loaded by unrelated class loaders)

Possible usages of class loaders



- Load resources bundled in JARs
- Load, unload, update modules at runtime
- Use different versions of a library at the same time
- Isolate different applications running within the same VM (static variables could be a problem otherwise)
- Exercise control over where the code comes from (e.g. a network)



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Reflective code-generation

Reflective code generation



- Basic Java reflection is limited
- Dynamic proxies are more powerful, but their level of granularity is the method
- We may need to change the behavior of a method at runtime
- Code generation is a solution
- Class-to-class transformation is an example of code generation

Class-to-class transformation



- Input: a class
- Output: another class, obtained by transforming the input
- Use reflection to examine the input class (no parser needed)
- Load generated classes dynamically at runtime

Generating `static` HelloWorld (1/2)



```
class HelloGenerator {
    public static void main(String[] args)
        throws Exception {
        // Step 1: generate class text on file
        PrintWriter pw = new PrintWriter( new
            FileOutputStream("Hello.java"));
        pw.println("... class text here ...");
        // Step 2: compile .java file into bytecode
        Process p = Runtime.getRuntime().exec(
            new String[]{"javac", "Hello.java"});
        p.waitFor();
        // continues on next slide
    }
}
```

Generating `static` HelloWorld (2/2)



```
// continues from previous slide
// If compilation went fine...
if(p.exitValue() == 0){
// now the runtime knows about the Hello class
// Step 3: use dynamically generated class
Class<?> helloObj = Class.forName("Hello");
Method m = helloObj.getMethod("main", String[].class);
// null target because 'main' is static
m.invoke(null, new Object[]{new String[]{}});
}
else{    /* handle I/O errors */ }

}
}
```