Java Reflection

Java Reflection

Explained Simply

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About the Author

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Introduction to Java Reflection

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1. Introduction

What is reflection?

- When you look in a mirror:
  - You can see your reflection
  - You can act on what you see, for example, straighten your tie
- In computer programming:
  - *Reflection* is infrastructure enabling a program can see and manipulate itself
  - It consists of *metadata* plus operations to manipulate the metadata
- *Meta* means self-referential
  - So metadata is data (information) about oneself

Widespread ignorance of Java reflection

- Typical way a developer learns Java:
  - Buys a large book on Java
  - Starts reading it
  - Stops reading about half-way through due to project deadlines
  - Starts coding (to meet deadlines) with what he has learned so far
  - Never finds the time to read the rest of the book
- Result is widespread ignorance of many "advanced" Java features:
  - Many such features are *not* complex
  - People just assume they are because they never read that part of the manual
  - Reflection is one "advanced" issue that is not complex

Is reflection difficult?

- When learning to program:
  - First learn iterative programming with if-then-else, while-loop, …
  - Later, learn recursive programming
- Most people find recursion difficult *at first*
  - Because it is an unusual way of programming
  - But it becomes much easier once you "get it"
- Likewise, many people find reflection difficult *at first*
  - It is an unusual way of programming
  - But it becomes much easier once you "get it"
  - Reflection seems natural to people who have written compilers (a parse tree is conceptually similar to metadata in reflection)
- A lot of reflection-based programming uses recursion

2. Metadata

Accessing metadata

- Java stores metadata in classes
  - Metadata for a class: `java.lang.Class`
  - Metadata for a constructor: `java.lang.reflect.Constructor`
  - Metadata for a field: `java.lang.reflect.Field`
  - Metadata for a method: `java.lang.reflect.Method`
- Two ways to access a `Class` object for a class:

```
Class c1 = Class.forName("java.util.Properties");

Object obj = ...;
Class c2 = obj.getClass();
```

- Reflection classes are inter-dependent
  - Examples are shown on the next slide

Examples of inter-relatedness of reflection classes

```
class Class {
    Constructor[] getConstructors();
    Field         getDeclaredField(String name);
    Field[]       getDeclaredFields();
    Method[]      getDeclaredMethods();
    ...
}

class Field {
    Class getType();
    ...
}

class Method {
    Class[] getParameterTypes();
    Class   getReturnType();
    ...
}
```


Metadata for primitive types and arrays

- Java associates a `Class` instance with each primitive type:

```
Class c1 = int.class;
Class c2 = boolean.class;
Class c3 = void.class;
```

Might be returned by `Method.getReturnType()` (→ `void.class`)

- Use `Class.forName()` to access the `Class` object for an array

```
Class c4 = byte.class;                // byte
Class c5 = Class.forName("[B");       // byte[]
Class c6 = Class.forName("[[B");      // byte[][]
Class c7 = Class.forName("[Ljava.util.Properties");
```

- Encoding scheme used by `Class.forName()`
  - B → byte; C → char; D → double; F → float; I → int; J → long; Lclass-name → class-name[]; S → short; Z → boolean
  - Use as many "["s as there are dimensions in the array

Miscellaneous Class methods

- Here are some useful methods defined in `Class`

```
class Class {
  public String getName(); // fully-qualified name
  public boolean isArray();
  public boolean isInterface();
  public boolean isPrimitive();
  public Class getComponentType(); // only for arrays
  ...
}
```


3. Calling constructors

Invoking a default constructor

- Use `Class.newInstance()` to call the default constructor
  Example:

```
abstract class Foo {
    public static Foo create() throws Exception {
        String className = System.getProperty(
                "foo.implementation.class",
                "com.example.myproject.FooImpl");
        Class c = Class.forName(className);
        return (Foo)c.newInstance();
    }
    abstract void op1(...);
    abstract void op2(...);
}
...
Foo obj = Foo.create();
obj.op1(...);
```

Name of property → "foo.implementation.class"

Default value → "com.example.myproject.FooImpl"

Invoking a default constructor (cont')

- This technique is used in CORBA:
  - CORBA is an RPC (remote procedure call) standard
  - There are many competing implementations of CORBA
  - Factory operation is called `ORB.init()`
  - A system property specifies which implementation of CORBA is used
- A CORBA application can be written in a portable way
  - Specify the implementation you want to use via a system property (pass -D<name>=<value> command-line option to the Java interpreter)
- Same technique is used for J2EE:
  - J2EE is a collection of specifications
  - There are many competing implementations
  - Use a system property to specify which implementation you are using

A plug-in architecture

- Use a properties file to store a mapping for *plugin name → class name*
  - Many tools support plugins: Ant, Maven, Eclipse, …

```
abstract class Plugin {
    abstract void op1(...);
    abstract void op1(...);
}
abstract class PluginManager {
    public static Plugin load(String name)
                                throws Exception {
        String className = props.getProperty(name);
        Class c = Class.forName(className);
        return (Plugin)c.newInstance();
    }
}
...
Plugin obj = PluginManager.load("...");
```


Invoking a non-default constructor

- Slightly more complex than invoking the default constructor:
  - Use `Class.getConstructor(Class[] parameterTypes)`
  - Then call `Constructor.newInstance(Object[] parameters)`

```
abstract class PluginManager {
    public static Plugin load(String name)
                                throws Exception {
        String className = props.getProperty(name);
        Class c = Class.forName(className);
        Constructor cons = c.getConstructor(
           new Class[]{String.class, String.class});
        return (Plugin)cons.newInstance(
                          new Object[]{"x", "y"});
    }
}
...
Plugin obj = PluginManager.load("...");
```

Passing primitive types as parameters

- If you want to pass a primitive type as a parameter:
  - Wrap the primitive value in an object wrapper
  - Then use the object wrapper as the parameter
- Object wrappers for primitive types:
  - `boolean` → `java.lang.Boolean`
  - `byte` → `java.lang.Byte`
  - `char` → `java.lang.Character`
  - `int` → `java.lang.Integer`
  - `...`

4. Methods

Invoking a method

- Broadly similar to invoking a non-default constructor:
  - Use `Class.getMethod(String name, Class[]parameterTypes)`
  - Then call `Method.invoke(Object target, Object[] parameters)`

```
Object obj = ...
Class c = obj.getClass();
Method m = c.getMethod("doWork",
              new Class[]{String.class, String.class});
Object result= m.invoke(obj, new Object[]{"x","y"});
```


Looking up methods

- The API for looking up methods is fragmented:
  - You can lookup a *public* method in a class or its ancestor classes
  - Or, lookup a public or non-public method *declared* in the specified class

A better name would have been `getPublicMethod()`

```
class Class {
    public Method getMethod(String name,
                            Class[] parameterTypes);
    public Method[] getMethods();
    public Method getDeclaredMethod(String name,
                            Class[] parameterTypes);
    public Method[] getDeclaredMethods();
    ...
}
```

Finding an inherited method

- This code searches up a class hierarchy for a method
  - Works for both public and non-public methods

```
Method findMethod(Class cls, String methodName,
                  Class[] paramTypes)
{
    Method method = null;
    while (cls != null) {
        try {
            method = cls.getDeclaredMethod(methodName,
                                           paramTypes);
            break;
        } catch (NoSuchMethodException ex) {
            cls = cls.getSuperclass();
        }
    }
    return method;
}
```


5. Fields

Accessing a field

- There are two ways to access a field:
  - By invoking get- and set-style methods (if the class defines them)
  - By using the code shown below

```
Object obj = ...
Class c = obj.getClass();
Field f = c.getField("firstName");
f.set(obj, "John");
Object value = f.get(obj);
```


Looking up fields

- The API for looking up fields is fragmented:
  - You can lookup a *public* field in a class or its ancestor classes
  - Or, lookup a public or non-public field *declared* in the specified class

A better name would have been `getPublicField()`

```
class Class {
    public Field   getField(String name);
    public Field[] getFields();
    public Field   getDeclaredField(String name);
    public Field[] getDeclaredFields();
    ...
}
```

Finding an inherited field

- This code searches up a class hierarchy for a field
  - Works for both public and non-public fields

```
Field findField(Class cls, String fieldName)
{
    Field field = null;
    while (cls != null) {
        try {
            field = cls.getDeclaredField(fieldName);
            break;
        } catch (NoSuchFieldException ex) {
            cls = cls.getSuperclass();
        }
    }
    return field;
}
```


6. Modifiers

Java modifiers

- Java defines 11 modifiers:
  - `abstract`, `final`, `native`, `private`, `protected`, `public`, `static`, `strictfp`, `synchronized`, `transient` and `volatile`
- Some of the modifiers can be applied to a class, method or field:
  - Set of modifiers is represented as bit-fields in an integer
  - Access set of modifiers by calling `int getModifiers()`
- Useful static methods on `java.lang.reflect.Modifier`:

```
static boolean isAbstract(int modifier);
static boolean isFinal(int modifier);
static boolean isNative(int modifier);
static boolean isPrivate(int modifier);
...
```


Accessing non-public fields and methods

- Both `Field` and `Method` define the following methods (inherited from `java.lang.reflect.AccessibleObject`):

```
boolean isAccessible();
void setAccessible(boolean flag);
static void setAccessible(AccessibleObject[] array,
                          boolean flag);
```

- Better terminology might have been "SuppressSecurityChecks" instead of "Accessible"
- Example of use:

```
if (!Modifier.isPublic(field.getModifiers()) {
    field.setAccessible(true);
}
Object obj = field.get(obj);
```

Hibernate uses this technique so it can serialize non-public fields of an object to a database

7. Further reading and summary

Further reading

- There are very few books that discuss Java reflection
  - An excellent one is *Java Reflection in Action* by Ira R. Forman and Nate Forman
  - It is concise and easy to understand
- Main other source of information is Javadoc documentation

Summary

- This chapter has introduced the basics of Java reflection:
  - Metadata provides information about a program
  - Methods on the metadata enable a program to examine itself and take actions
- Reflection is an unusual way to program:
  - Its “meta” nature can cause confusion *at first*
  - It is simple to use once you know how
- The next chapter looks at a reflection feature called *dynamic proxies*

Dynamic Proxies

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What is a proxy?

- Dictionary definition: “a person authorized to act for another”
  - Example: if you ask a friend to vote on your behalf then you are “voting by proxy”
- In computer terms, a proxy is a delegation object (or process)
- Used in remote procedure call (RPC) mechanisms:
  - Client invokes on a (local) proxy object
  - Proxy object sends request across the network to a server and waits for a reply
- Some companies set up a HTTP proxy server:
  - Firewall prevents outgoing connections to port 80
  - So web browsers cannot connect to remote web sites directly
  - Web browsers are configured to connect via the company’s proxy server
  - Proxy server can be configured to disallow access to eBay, Amazon, …

Dynamic proxies in Java

- Java 1.3 introduced dynamic proxies
  - The API is defined in the `java.lang.reflect` package

```
class Proxy {
    public static Object newProxyInstance(
                         ClassLoader loader,
                         Class[] interfaces,
                         InvocationHandler h) throws ...
    ...
}

interface InvocationHandler {
    Object invoke(Object proxy,
                  Method m,
                  Object[] args) throws Throwable;
}
```

Steps required to create a dynamic proxy

- Step 1:
  - Write a class that implements `InvocationHandler`
  - Your implementation of `invoke()` should:
    - Use `Method.invoke()` to delegate to the target object
    - Provide some “added value” logic
- Step 2:
  - Call `Proxy.newInstance()`, with the following parameters:
    - `targetObj.getClass().getClassLoader()`
    - `targetObj.getClass.getInterfaces()`
    - `InvocationHandler` object “wrapper” around the target object
- Step 3:
  - Typecast the result of `Proxy.newInstance()` to an interface implemented by the target object

How does this work?

- The `Proxy.newProxyInstance()` method:
  - Uses runtime code generation techniques
  - Generates a “hidden” class with a name of the form `$Proxy<int>` (Use of “`$`” prevents namespace pollution)
  - Generated class:
    - Implements the specified interfaces
    - Each method puts parameters into `Object[]` and calls `InvocationHandler.invoke()`
- Can use a dynamic proxy *only if* a class implements 1+ interfaces
  - Use of interfaces is a good programming practice
  - So this requirement is not a problem in practice

Sample code

```
public class Handler implements InvocationHandler {
    private Object target;

    private Handler(Object target) {
        this.target = target;
    }

    public Object invoke(Object proxy, Method m,
                         Object[] args) throws Throwable
    {
        Object result = null;
        try {
            ... // added-value code
            result = m.invoke(target, args);
        } catch(InvocationTargetException ex) {
            ... // added-value code
            throw ex.getCause();
        }
        return result;
    }
    ... // continued on the next slide
```

The `proxy` parameter is usually ignored

Sample code (cont')

```
    ... // continued from the previous slide

    public static Object createProxy(Object target)
    {
        return Proxy.newProxyInstance(
                    target.getClass().getClassLoader(),
                    target.getClass().getInterfaces(),
                    new Handler(target));
    }
}
```

Example uses for dynamic proxies

- Added-value code might:
  - Enforce security checks
  - Begin and commit or rollback a transaction
  - Use reflection & recursion to print details of all parameters (for debugging)
- In a testing system, a proxy might “pretend” to be target object
  - Returns “test” values instead of delegating to a real object
  - EasyMock (www.easymock.org) makes it easy to write tests in this way

Example Uses of Java Reflection

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1. Basic uses of Java reflection

Ant

- Ant reads build (compilation) instructions from an XML file
- Ant is hard-coded to know how to process top-level elements
  - `property`, `target`, `taskdef` and so on
- Each Ant task (used inside `target` elements) is a plug-in
  - See example Ant build file on the next slide for examples of tasks
- Many task plug-ins are bundled with the Ant distribution (`jar`, `javac`, `mkdir`, …)
  - A properties file provides a mapping for *task-name* → *class-that-implements-task*
- Users can use `taskdef` to tell Ant about user-written tasks
  - See example on the next slide

Example Ant build file

```
<?xml version="1.0"?>
<project name="example build file" ...>
    <property name="src.dir" value="..."/>
    <property name="build.dir" value="..."/>
    <property name="lib.dir" value="..."/>

    <target name="do-everything">
        <mkdir dir="..."/>
        <mkdir dir="..."/>
        <javac srcdir="..." destdir="..." excludes="..."/>
        <jar jarfile="..." basedir="..." excludes="..."/>
        <foo .../>
    </target>

    <taskdef name="foo" classname="com.example.tools.Foo"/>
</project>
```


Auto-completion in a text editor

- Some Java editors and IDEs provide auto-completion
  - Example: you type "`someObj.`" and a pop-up menu lists fields and methods for the object's type
- The pop-up menu is populated by using Java reflection

JUnit

- JUnit 3 uses reflection to find methods whose names start with “test”
- The algorithm was changed in JUnit 4
  - Test methods are identified by an annotation (Annotations were introduced in Java 1.5)
  - Reflection is used to find methods with the appropriate annotation

Spring

- Below is an extract from a Spring configuration file:

```
<?xml version="1.0"?>
<beans ...>
  <bean id="employee1"
    class="com.example.xyz.Employee">
    <property name="firstName" value="John"/>
    <property name="lastName" value="Smith"/>
    <property name="manager" ref="manager"/>
  </bean>

  <bean id="manager"
    class="com.example.xyz.Employee">
    <property name="firstName" value="John"/>
    <property name="lastName" value="Smith"/>
    <property name="manager" ref="manager"/>
  </bean>

  ...
</beans>
```

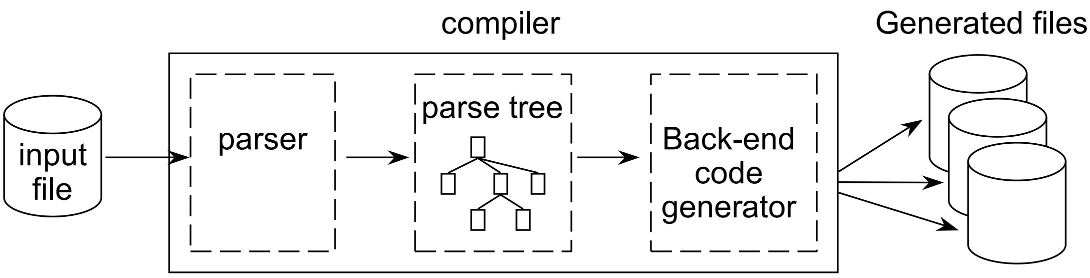
Spring (cont')

- Spring uses reflection to create an object for each `bean`
  - The object's type is specified by the `class` attribute
- By default, the object is created with its default constructor
  - You can use `constructor-arg` elements (nested inside `bean`) to use a non-default constructor
- After an object is constructed, each `property` is examined
  - Spring uses reflection to invoke `obj.setXxx(value)`
    - Where `Xxx` is the capitalized name of property `xxx`
  - Spring uses reflection to determine the type of the parameter passed to `obj.setXxx()`
  - Spring can support primitive types and common `Collection` types
  - The `ref` attribute refers to another `bean` identified by its `id`

2. Code generation and bytecode manipulation

Code generators

- Most compilers have the following architecture



- Java's reflection metadata is conceptually similar to a parse tree
- You can build a Java code generation tool as follows:
  - Do *not* write a Java parser. Instead run the Java compiler
  - Treat generated .class files as your parse tree
  - Use reflection to navigate over this "parse tree"

Code generators (cont')

- Compile-time code generation in a project:
  - Use technique described on previous slide to generate code
  - Then run Java compiler to compile generated code
  - Use Ant to automate the code generation and compilation
- Runtime code generation:
  - Use techniques described on previous slide to generate code
  - Then invoke a Java compiler *from inside* your application:
    - Can use (non-standard) API to Sun Java compiler
      - Provided in `tools.jar`, which is shipped with the Sun JDK
    - Or can use Janino (an open-source, embeddable, Java compiler)
      - Hosted at www.janino.net
  - Finally, use `Class.forName()` to load the compiled code

Uses for runtime code generation

- Runtime code generation is used…
- By JSP (Java Server Pages)
  - To generate servlets from .jsp files
- By IDEs and debuggers
  - To evaluate Java expressions entered by user

Uses for Java bytecode manipulation

- Compilers:
  - Write a compiler for a scripting language and generate Java bytecode
    - Result: out-of-the-box integration between Java and the language
  - Groovy (groovy.codehaus.org) uses this technique
- Optimization:
  - Read a .class file, optimize bytecode and rewrite the .class file
- Code analysis:
  - Read a .class file, analyze bytecode and generate a report
- Code obfuscation:
  - Mangle names of methods and fields in .class files
- Aspect-oriented programming (AOP):
  - Modify bytecode to insert “interception” code
  - Generate proxies for classes or interfaces
  - Spring uses this technique

Tools for bytecode manipulation

- Example open-source projects for bytecode manipulation:
  - ASM (http://asm.objectweb.org/)
  - BCEL (http://jakarta.apache.org/bcel/)
  - SERP (serp.sourceforge.net)
- CGLIB (Code Generation LIBrary):
  - Built on top of BCEL
  - Provides a higher-level API for generating dynamic proxies
  - Used by other tools, such as Spring and Hibernate

3. Summary

Summary

- A *lot* of tools use Java reflection:
  - Plugins to extend functionality of an application (Ant)
  - Auto-completion in Java editors and IDEs
  - Use naming conventions of methods to infer semantics (JUnit test methods)
  - Tie components together (Spring)
  - Compile-time code generation
  - Runtime code generation
    - Generate proxies
    - Generate servlets from a markup language (JSP)
  - Evaluate Java expressions entered interactively by a user