

Java Reflection

Explained Simply

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About the Author

Ciaran McHale has a Ph.D. in computer science from Trinity College Dublin. He has been working for IONA Technologies (www.iona.com) since 1995, where he is a principal consultant. His primary talent is the ability to digest complex ideas and re-explain them in simpler ways. He applies this talent to subjects that stir his passion, such as multi-threading, distributed middleware, code generation, configuration-file parsers, and writing training courses. You can find details of some of his work at his personal web site: www.CiaranMcHale.com. You can email him at Ciaran@CiaranMcHale.com.

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1. Introduction

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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

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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();
    ...
}
```

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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()

- 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

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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
    ...
}
```

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3. Calling constructors

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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(...);

```

Diagram annotations:

- Name of property**: points to the value of the `System.getProperty()` call.
- Default value**: points to the 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 op2(...);
}
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

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

A better name would have been `getPublicMethod()`

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

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

A better name
would have been
getPublicField()

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;
}
```

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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);
...
```

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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

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7. Further reading and summary

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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

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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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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

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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;
}
```

Dynamic Proxies

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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.newInstance()` 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.newInstance(
        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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Example Uses of Java Reflection

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1. Basic uses of Java reflection

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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 Uses of Java Reflection

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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>
```

Example Uses of Java Reflection

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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

Example Uses of Java Reflection

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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

Example Uses of Java Reflection

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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>
```

Example Uses of Java Reflection

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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`

Example Uses of Java Reflection

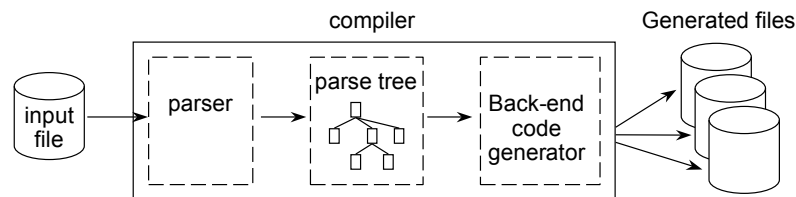
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2. Code generation and bytecode manipulation

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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"

Example Uses of Java Reflection

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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

Example Uses of Java Reflection

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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

