CS 121
Software Engineering Foundations

Reflection

Introduction

- Reflection makes classes, methods, and fields into *first class objects* that exist at run time
  - Can determine fields and methods of class
  - Can instantiate class given a `String` containing the name
  - Can invoke methods given a `String` with method name
  - Can create classes (in a certain way) at runtime
- Reflection does not
  - Add any expressive power to the language, in theory
    - With or without reflection, Java is *Turing Complete*
  - Solve every problem
    - Reflection is a sledgehammer that can do certain things that are difficult to achieve any other way
    - But it should be used sparingly, preferably not at all

java.lang.Class

- An instance of `Class` represents a class
  - You can use it to get information about its fields/methods
  - Most uses of reflection start with a `Class`
  - Even primitive types have a `Class`
- Where to get one of these objects?
  - `Class<?> c = “hello”.getClass();`
  - `Class<?> c = String.class;`
  - `Class<?> c = Class.forName(“java.lang.String”);`
  - Here, the `<?>` means the exact class is unknown, which is a conservative assumption
- What is the `Class` of a class? `Class`, of course!
  - `“hello”.getClass().getClass() == Class.class;`

java.lang.reflect.Constructor

- If we want to make an instance of the class, we need to get one of its constructors first

```
Class<?> c = A.class;
Constructor<?> cons = c.getConstructor(String.class,
                                       int.class);
Object o = cons.newInstance(“foo”, 42);
A a = (A) o;
```

  - Because we didn’t indicate what class this constructor is for (parameter is `<?>`), we have to downcast the return of `newInstance`

- Omitted: lots of checked exceptions
  - `getConstructor` might raise `NoSuchMethodException`
  - `newInstance` might raise `IllegalAccessException`, …
  - Generally, always need to use `try-catch` with reflection

Methods and Fields

```
Class<?> c = A.class;
Method<?> meth = c.getMethod("m", int.class);
A a = …;
Object o = meth.invoke(a, 42); // call a.m(42);
```

```
Class<?> c = A.class;
Field<?> fld = c.getField("f");
A a = …;
Object A_f = fld.get(a);  // return a.f
```

- Notice that a `Method` and `Field` (from `java.lang.reflect`) describe an elt of a class
- To invoke a `Method`, pass `this` as the first argument
- To access a `Field`, pass `this` as the argument

Hello, World!

```
import java.io.*;
import java.lang.reflect.*;

public static void main(String[] args)
    throws Exception {
  Field f = System.class.getField(“out”);
  PrintStream out = (PrintStream) f.get(null);
  Method m = PrintStream.class.getMethod(“println”,
                                         String.class);
  m.invoke(out, “Hello, world!”);
}
```

- Exercise: use reflection to call `System.out.println(“Hello ”.concat(“world!”));`
- Well, that doesn’t seem very good!
  - Why would we ever want to use reflection?

Design Patterns with Reflection

Factory Methods

- Recall that in the factory pattern, we create objects through a method call rather than using `new` directly
- We could use reflection to create objects by name
- Example: Create objects based on names in map

```
// Assume Pawn is a class, Pawn extends Piece
HashMap<char, String> hm;  // map from ‘p’ to ‘Pawn’

String cname = hm.get(‘p’);
Class<?> c = Class.forName(cname);
Constructor cons = c.getConstructor();
Piece p = (Piece) cons.newInstance();
```

Interpreter

- Take various actions depending on a string
  - “pwd” → call pwd()
  - “cd <dir>” → call cd(“<dir>”)
- Straightforward implementation

```
if (str.equals(“pwd”)) { pwd(); }
else if (str.matches(“cd .*”)) { cd(…); }
…
```

- Reflective implementation

```
String[] split = str.split(“ ”);
String cmd = split[0];
String[] args = Arrays.copyOfRange(cmd, 1, split.length-
Method m = this.class.getMethod(cmd[0]);
m.invoke(this, args);
```

  - Concise, easy to extend

Security Warning!

- The previous example is actually a **BAD IDEA**
- What if `str` is controlled by an *adversary*?
  - Someone who is *trying* to do something bad
  - Normal users work around bugs; adversaries look for them!
- An adversary could set `str` to
  - The name of a method they shouldn't be able to call
  - The name of a nonexistent method—leads to crash
- Who might be an adversary?
  - Someone sending data over the internet
  - A local user with fewer privileges than the app
- KEY RULE: Never treat data that is not directly from the program as code

Testing

- Invoke all methods that begin with `test`

```
// o is an instance of some Test class
Class c = o.class;
Method[] meths = c.getMethods();
for (Method m : meths) {
  if (m.getName().startsWith("test")) {
    m.invoke(o)
  }
}
```

  - We'll learn about JUnit a little later, which does this

Double Dispatch

- Recall in the Visitor pattern, invoking `o1.accept(o2)` calls a method that depends on the run-time type of `o1` and the run-time type of `o2`
- We can implement this with reflection!

```
class C {
  Object m(C1a x, C1b y) { … }
  Object m(C2a x, C2b y) { … } …
}
// call m method based on run-time type of x, y
Object call_m(Object x, Object y) {
  C c = …;
  // now we look up run-time types of x and y
  Method m = c.class.getMethod("m",
                               x.getClass(), y.getClass());
  m.invoke(c, x, y);
}
```

Dynamic Proxies

- Recall the Proxy pattern: wrap an object to add extra logic before or after calls to its methods
- Java has *dynamic proxy* support to create a wrapper on-the-fly

```
import java.lang.reflect.*;

public class MyProxy implements InvocationHandler {
  Object invoke(Object proxy, Method method,
                Object[] args) {
    // proxy = o, method = m, args[] = { “foo” }
} }
interface I { void m(String x); }
Class<?> interfaces = new Class<>[] { I.class };
InvocationHandler handler = new MyProxy();
I o = (I) Proxy.newProxyInstance
   (I.class.getClassLoader(), interfaces, handler);
o.m(“foo”);
```

Serialization

- Can use reflection to automatically serialize objects

```
Writer w = …;
void serialize(Object o) {
 Class c = o.getClass();
  w.write(c + “\0”);  // add null as terminator
  Field[] fs = c.getFields();
  for (Field f : fs) {
    w.write(f.getName() + “\0”);
    serialize(w); // serialize the field value
} }
```

- Above code doesn’t work with cycles…

Reflection Disadvantages

- Extremely verbose
- Potentially opens up security concerns
- Misses out on compile-time type checking
  - E.g., trying to invoke a method with the wrong name or wrong arg types becomes a run-time exception
- Large performance penalty compared to direct calls
  - Overhead of extra method calls plus compiler can't optimize reflective calls very well, in general
- Summary: Use with caution or not at all
  - Never use it if you don't have a very good reason