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Introspection and reflexivity

Principles and application to Java

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Agenda

- RTTI in Java
- Reflexivity: definitions
- Analysing a class
- Analysing an object
- Example
- Handling methods
- Annotation

  - By default, examples are based on Java 2 / JDK 1.4.x
  - Zoom on extensions brought since Java 5 and 6

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The class Class

RTTI in java

Run-Time Type Identification

- Java is maintaining what is called Run-Time Type Identification (RTTI) on all objects
- Enables one to know the *real* class of an object
- Enables the runtime system to implement dynamic binding (what method is really called)

```
GraphicObject o = new Circle();
o.draw(); // from Circle or GraphicObject ?
```

The class Class and RTTI

- A class allows for accessing RTTI, the class Class

```
Person p = new Person("Maurice");
Person p1 = new Professor("Yoda")
Class cl = p.getClass();
System.out.println(cl.getName() +  " " +
  p.getNom());
```

Displays

```
"Person Maurice"
"Professor Yoda" with p1…
```

The .class suffix

- An object of type Class can be obtained:

```
Class cl1 = Professor.class;
Class cl2 = int.class;
Class cl3 = double.class;
…
```

- Useful to check the type with predefined types

Name = Class ?

- A class can be obtained from its name (~ functional languages)

```
String className =
  "com.wars.star.Professor";
Class cl = Class.forName(className);
```

- **`className`** can be the name of an interface or a class
- Useful to load classes which name is not known in advance

Create instances without new

- Using the method newInstance() of the class **`Class`**

```
String className = "Professor";
Class cl = Class.forName(className);
Object o = cl.newInstance();
```

- Note : it exists newInstance(Object [] params) of class Constructor (java.lang.reflect)

Methods of the class Class (Java 2)

```
String getName();
Class getSuperClass();
Class [] getInterfaces();
boolean isInterface();
String toString();
static Class forName(String name);
Object newInstance();
```

Methods of the class **Class<T>** (Java 5)

```
String getName();
TypeVariable<Class<T>>[] getTypeParameters();
Class<? super T> getSuperClass();
Class [] getInterfaces();
boolean isInterface();
String toString();
static Class<?> forName(String name);
T newInstance();
Constructor<T> getConstructor( Class...
  parameterTypes);
```

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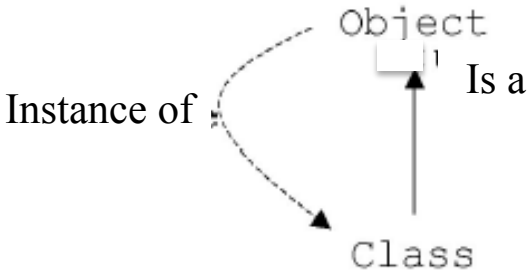
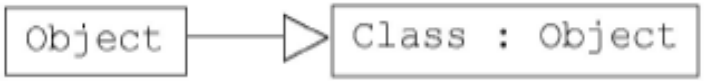
Reflexivity

Definition

- A « reflexive » system is able to represent itself
  - For computer langages, reflexivity is expressed as the capability for a language to describe aspects considered as implicit in the language
  - In the case of an object language:
    - Access to the class of an object : classes are objects
    - Instantiation of classes which name is only known at runtime
    - Access to attribues and methods of objects
    - Method invocation (message passing) with the method name only known at runtime

Meta-circular object schema





- Classes are instances of *Class* and thus are objects
  - Have attributes: attributes of the instances, their methods…
  - Have methods (message can be passed to them)
  - Can create instances
  - Enable to know value of attributes
  - Can call methods
- The Object class is a class, thus an instance of Class, it can then be handled in the same way

Reflexivity, introspection, meta-programming ?

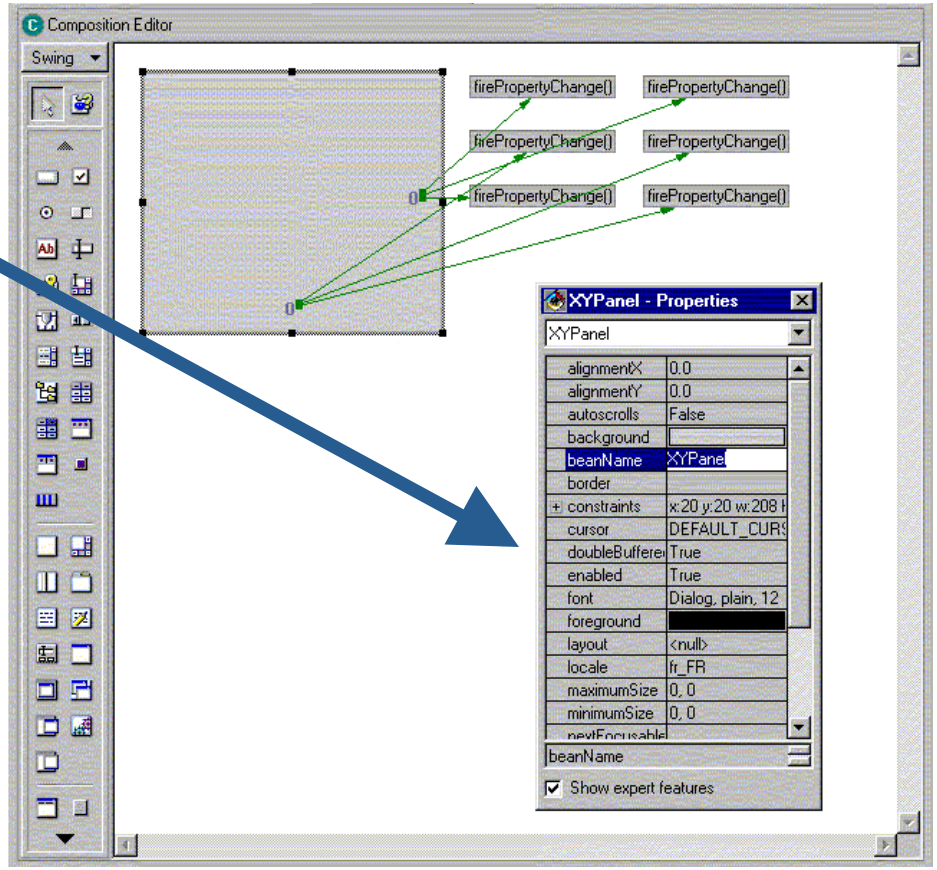
- Introspection
  - Know/inspect classes, objects, methods at runtime
  - Do it in the same language = reflexive introspection
- Meta-programming
  - Capability to modify language mecanisms using a META program
- Meta + reflex = inspect and modify behavior
- Java = reflexive introspection, no meta-programming protocol

How to do it in Java ?

- Class **`Class`** minimal in Java 1.0
- Improvement from version 1.1 due to Java Beans and RMI
  - Tools (RAD: JBuilder, Visual Café, Eclipse …) need to deal with new classes at runtime (beans)
  - Classes are moved around in distributed architectures
- Such features are provided by the package **`java.lang.reflect`**
  - Analyse classes at runtime
  - Inspect objects at runtime
  - Write a generic toString() method
  - Handle generic arrays
  - Handle methods as pointers to function like in C/C++…

Reflexivity in a RAD tool

- Display of properties in an editing window
- Property = attribute with accessor and modifier (optional)
- Dynamic query on the class looking for `get...()` and `set...()`



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Analysing a class

Analysing a class

- Three main classes in **`java.lang.reflect`**
  - **`Field, Method, Constructor`**
  - All have **`getName()`**
  - Field has **`getType()`** which returns an object of type **`Class`**
  - **`Method`** and **`Constructor`** have methods to get the return type and parameter types

Analysing a class (cont'd)

- These three classes have **`getModifiers()`** which returns an **`int`**, which bytes set to 0 or 1 mean static, public, private, etc…
  - Static methods from **`java.lang.reflect.Modifier`** are used to get these values
  - **`Modifier`** has methods such as **`toString(int)`** **`isFinal(int)`**, **`isPublic(int)`**, **`isPrivate(int)`**

Example

- During the lab, a program will be able to produce, from a class name and a .class file:

```
Class java.lang.double extends java.lang.number {
   public static final double POSITIVE_INFINITY;
   public static final double NEGATIVE_INFINITY;
   public static final double NaN;
   …
   public static java.lang.Double(double);
   public static java.lang.Double(java.lang.String);
   …
   public static java.lang.String toString(double);
   public static boolean isNaN(double);
   public boolean equals(java.lang.Object);
   …
}
```

Methods of the class Class

- **`Field[] getFields()`**
  - Returns only public attributes, local and inherited
- **`Field[] getDeclaredFields()`**
  - Returns all attributes local only
- These two methods returns an array of null size if
  - No attributes
  - The class is actually a predefined type (int, double…)

Methods of Class (cont'd)

- **`Method[] getMethods()`**
  - Returns only public, local and inherited, methods
- **`Method[] getDeclaredMethods()`**
  - Returns all, local only, methods
- **`Constructor[] getConstructors()`**
  - Returns all public constructors
- **`Constructors[] getDeclaredConstructors()`**
  - Returns all constructors

Methods of Field, Method, Constructor

- `Class getDeclaringClass()`
- `Class[] getExceptionTypes()`
  - (Constructor and Method only)
- `int getModifiers()`
- `String getName()`
- `Class[] getParameterTypes()`
  - (Constructor and Method only)

Lab : a class analyser

- Write a method
- **`analyseClass(String className)`**
- That displays all it is possible to obtain on a class which name is given as parameter

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Analysing an object at runtime

Analysing an unknown object?

- Till now, we can
  - Determine names and types of the attributes of an object
  - Obtain from the object, its type (another object, of type Class)
  - Call getDeclaredFields() on the obtained object…
- We now want to obtain the content of an object, ie the content of its attributes
  - We don't know the object in advance, we don't know its class…

Accessing the value of an attribute

- Use the method **`get()`** of class **`Field`**
  - If **`f`** is an object of type **`Field`**
    - **`f = field[i];`**
  - If **`obj`** is an object of the class from which **`f`** is an attribute
  - Then **`f.get(obj)`** returns the value of the attribute **`f`** of the object **`obj`**

Example (in french ;-))

```
public class Personne {
    private String nom;
    private String prenom;
    private int age
    public Personne(String nom, String prenom, int age) {
        this.nom = nom;
        this.prenom = prenom;
        this.age = age;
    }
}
```

Example (cont'd)

```
Personne p = new Personne("Chombier",
  "Maurice", 47);
…
Class cl = p.getClass();
Field f = cl.getField("nom");
Object v = f.get(p);
System.out.println(v); // displays "Chombier"
```

- But… This does not work!
  - As the attribute « nom » is **`private`** !
  - Raises an **`IllegalAccessException`**

Example (cont'd)

- The Java security manager enables one to get the attributes, but not always their value (think « password »)
- Possible solution:
  - Change the attribute to public (so so)
  - Put the code in the class Personne (so so)
  - Use **AccessibleObject.setAccessible(AccessibleObject[] array, boolean flag)**
    - Allows, for example, for giving access to private attributes
    - May also not work if the security manager did not give authorization (java.policy… cf. java rmi)
      - Then raises a **`SecurityException`**

Example (cont'd)

- What happens if the attribute is of a predefined type?
  - `f.get(obj)` returns an `Object` !
- In this case, it is the corresponding class which is chosen: `Integer, Double, Float`, etc…

```
Field f = cl.getField("age"); // age is an int
Object v = f.get(p);          // v is an Integer
```

- With JDK 1.3 et 1.4 :
  - `f.getInt(), f.getDouble(),` etc…
- With Java 5 and on:
  - Auto-boxing simplifies the notation

Lab: a generic toString method

- Quite often, the toString method is redefined to describe an object by displaying values of its attributes.
- With reflexivity, it is possible to:
  - Write a method once
  - Place it in the classes source or quite high in a class hierarchy
  - The code is thus written once!

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Usage example: a growing array

The Array class from java.lang.reflect

- Common issue: a array of objects
  - Of a given type
  - And the array is full
- We can make it grow!

```
Personne[] tab = new Personne[10];
…
// the array is full
tab = (Personne[]) growArray(tab);
```

How to do it?

- Let's try this:

```
static Object[] growArray(Object[] tab) {
    int newSize = tab.length * 11/10 + 10;
    Object[] newArray = new Object[newSize];
    System.arrayCopy(tab, 0, newArray, tab.length);
    return newArray;
}
```

- Problem: the type **`Object[]`** can not here be type*casted* in **`Personne[]`**
- Why?

Methods of Array and Class classes

- InArray
  - `static Object newInstance(Class componentType, int length)`
  - `static int getLength()`
  - `boolean isArray()`
- In Class
  - `Class getComponentType()`, does not apply on an Array
  - Ex : `Class type = o.getClass().getComponentType();`
  - `o` must be anArray, and `type` represents the type of the array elements.

Lab: modify the preceding code

- Solution: use reflexivity to create a new array of the same type as the original array
- During the lab, modify **`Object[] growArray()`**
- … so that it works!
  - Think at using methods from **`Array`** and **`Class`**
  - Test with **`int[]`** ! Trap ahead!

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Pointers on functions?

Pass a parameter to a function, of type Method ?

- Emulate some pointers to functions ?

```
public print(double start, double end, double step,
  Method f) {
    for(double x = start; x < end; x+= step) {
       f(x);
    }
}
```

- Not so easy!

Calling a method

- The class Method has

```
Object invoke(Object o, Object[] args);
Object invoke(Object obj, Object... args);      // Java 5
```

  - `o` is the object which is going to receive the message
    - For a static method, `o` is `null`
  - `args` is the parameter list

- Example
  - To emulate `yoda.getNom()` where `yoda` is an instance of Personne and `f` represents `getNom()`

```
String n = (String) f.invoke(yoda, null);
```

Calling a method (cont'd)

- With predefined types, use « wrapper classes"

`Integer, Float, Double`, etc…

- Example with **`f`** that represents **`setAge(int age)`** of the class Personne

```
// JDK 1.2 to 1.4
Object[] args = {new Integer(735)};
f.invoke(yoda, args);

// Java 5 : Autoboxing + variable argument list
f.invoke(yoda, 735);
```

How to obtain an object of type Method ?

- Use getMethod(…) or getDeclaredMethods() of class Class
- Due to overloading, on must be able to precise types of parameters with **`getMethod(…)`**

```
Method getMethod(String name, Class[] args)
Method getMethod(String name, Class... args) // Java 5
```

- Example

```
m1 = Personne.class.getMethod("getNom", null);
m2 = Personne.class.getMethod("setAge",
                 new Class[] {int.class});
// Java 5
m2 = Personne.class.getMethod("setAge",int.class);
```

Other features

- Class Proxy
  - Static methods to dynamically create classes and instances *proxy*
- A proxy class (dynamic) is a class that implements a list of interfaces, specified at runtime
  - With no existing **text** class
- Reflexivity allows for creating new instances
- Pros?
  - Create instances compatible with several interfaces (easier for adaptation), with no class writing beforehand

New reflexive features in Java 5

- Metadata…
  - Annotations @... In the Java code
  - Content of the annotations accessible by introspection at runtime
- Genericity is handled
  - Class (concept of type and paramterized type)
- Autoboxing of base types
  - Eases the extraction of values from these types

Annotations in Java

- An annotation allows for marking some elements of the Java language so to add some particularities.
- These annotations can then be used at compile or execution time so to automate some tasks

```
@MyAnnotation
public class MyClass {
   /* ... */
}
```

- *Standards* annotations : @Deprecated, @Override, @SuppressWarnings("deprecation")
- Meta-annotations (to annotate other annotations) :
  - @Documented, @Inherit
  - @Retention(RetentionPolicy.SOURCE ou .CLASS ou .RUNTIME)
  - …

Creation of an annotation

- Creation

```
import java.lang.annotation.*;
import static java.lang.annotation.RetentionPolicy.SOURCE;

@Documented
@Retention(SOURCE)
public @interface TODO {
   /* Message describing the task */
   String value();
}
```

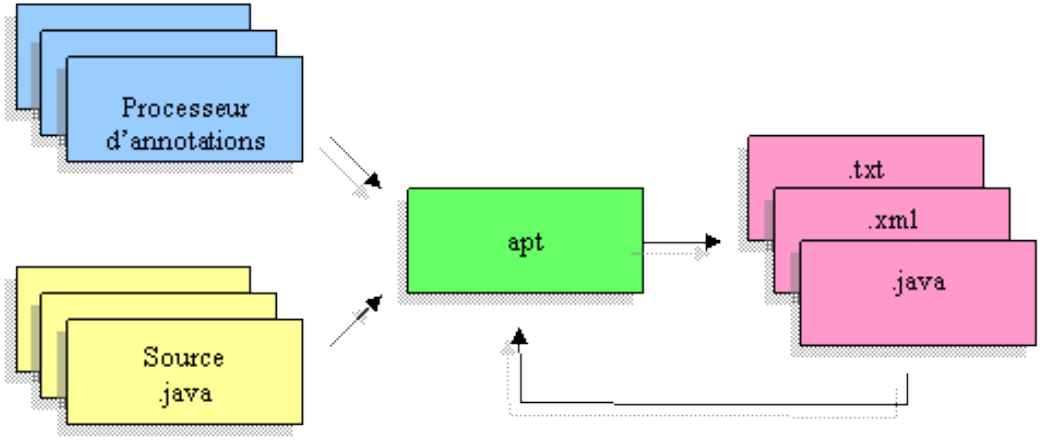
Attribute (limited type)

- Usage

```
@TODO(value="Code this ASAP...")
   public void ZeMethod () {
     …
```

Using annotations

- apt (annotation processing tool), Java 5



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- Introspection : getAnnotations on all elements : Class, Method, etc.
- Java (Java 6) compiler: API Pluggable Annotation Processing
  - External tools are not needed anymore